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ALLIS-CHALMERS

Electrical REVIEW

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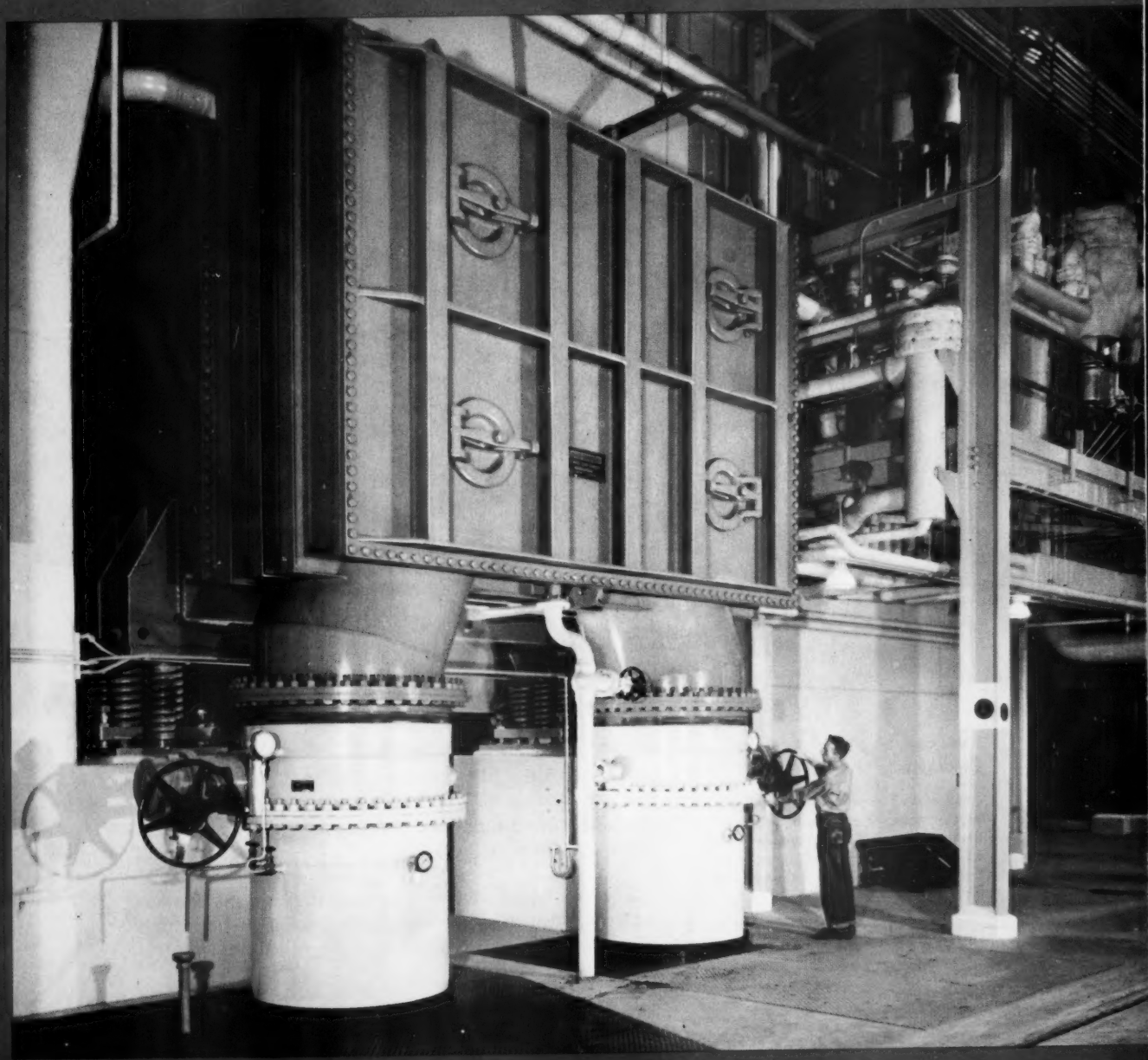

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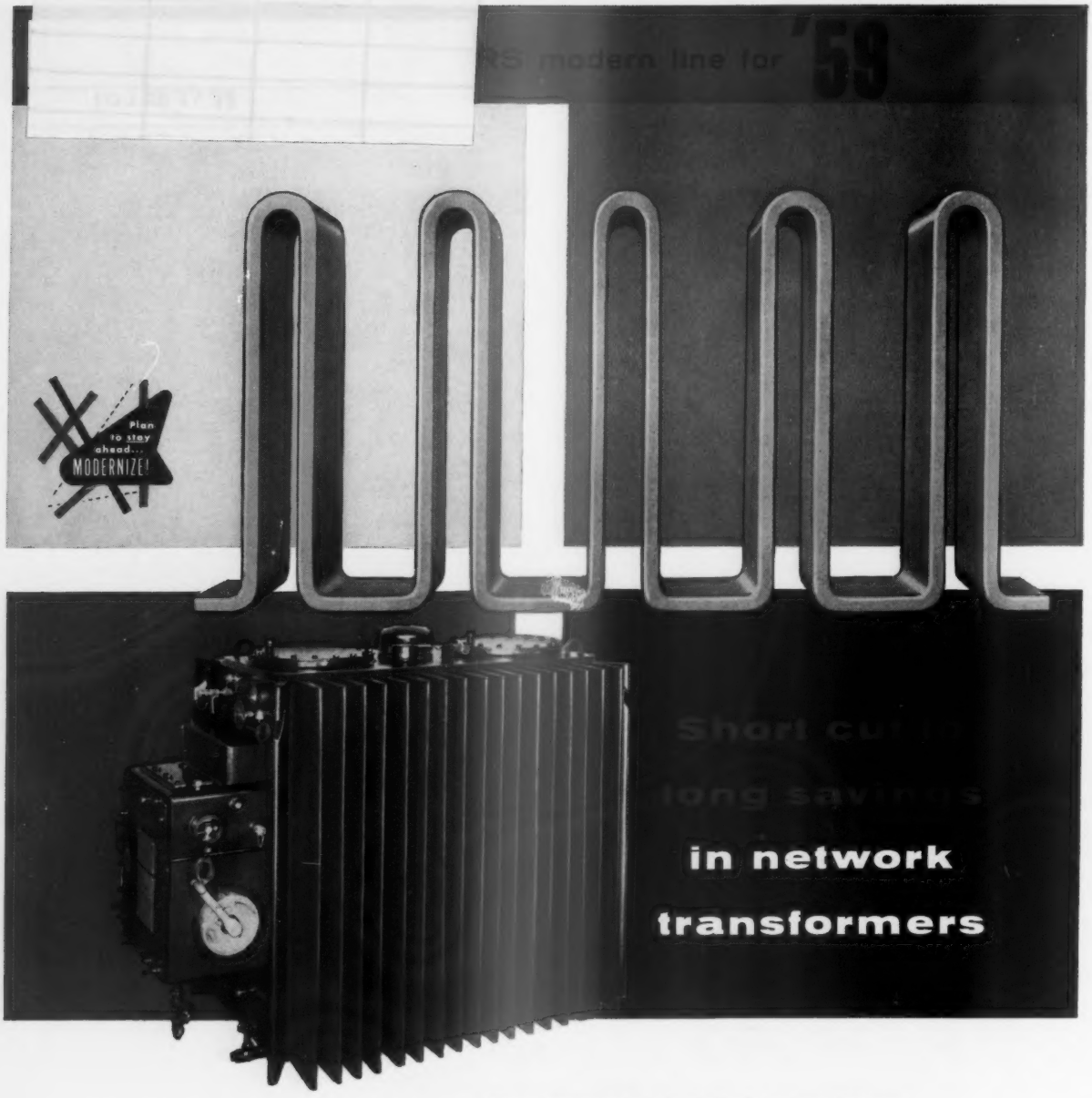

Corrugated tank surface simplifies cleaning and painting

Fluted tank design with its flowing surface continuity adds years of serviceability because: (1) Sharp corners and crevices are eliminated. (2) Easy visual inspection facilitates checking surface condition. (3) When required, reconditioning is simplified.

The proved maintenance economy of corrugated cooling surfaces is just one of the many more-for-your-money features of the new Allis-Chalmers network transformer.

Reduced Size and Weight Cut Installation Costs

Smaller vault requirements **per kva is another economy advantage of this redesigned unit. With more compact units to handle, work crew efficiency is increased. And, of course, increased kva may be installed in existing vaults.**

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ALLIS-CHALMERS

ALLIS-CHALMERS
Electrical REVIEW

THE COVER

SINGLE-PASS CONDENSER has 6240 28-ft tubes with 40,000 sq ft of condensing surface. Serving Wisconsin Public Service Corporation's Pulliam Station, this condenser requires 65,000 gpm of circulating water. High vacuum operation is possible because of the cold lake water condition. An article on condenser design trends starts on page 28.

Allis-Chalmers Staff Photo by Frank Hart

Allis-Chalmers

ELECTRICAL REVIEW

Vol. XXIV No. 3

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MODERNIZING HYDRAULIC TURBINES

HEAD INCREASE from 275 to 325 feet plus new runners and gates will bring Seattle City Light's Gorge Powerhouse capacity up from 108,000 to 165,000 kw. New structure will be approximately 670 feet long and 285 feet high. Two gates, each 47 feet long and 50.5 feet high, will control the flow over the spillway.

by G. E. HOCHWALT, JR.
Chicago District Office
Allis-Chalmers Mfg. Co.

Knowledge gained from modern test facilities points the way to gains in capacity by rehabilitating and modernizing older hydraulic turbine installations.

MANY HYDRO STATIONS are operating below their potential capacity, and consequently their full possible value to the power system is not being realized.

These stations in most cases have been in operation for many years and their rated capacities may have been selected without allowance for changes that have occurred, such as closer regulation of the river flowage due to storage, new plants located either upstream or downstream, and various other possible causes. In certain cases the turbines can be modified to meet present requirements more closely. These changes are often comparatively minor and involve relatively low cost.

Plant modernization has been accomplished over the years with considerable success. With the facilities now available, the approach to these problems can be placed on a far more exact and scientific basis and the improved results can be predicted within close limits.

Large test facilities needed

Figure 1 is a layout of a high head cavitation test stand. In this test stand it is possible to test medium and high specific speed Francis wheels and all Kaplan and propeller models under heads equal to those of prototypes up to approximately 300 feet.

This high head test facility is used not only for such basic research as the development of runners with improved cavitation and better operating characteristics, draft tube and water passage studies, but is also used to conduct formal contract model acceptance tests duplicating field conditions.

The arrows in Figure 1 indicate the course of the water through the test stand. Starting at the pumps, the water flows through the discharge header, venturi meter, intake header, butterfly valve, vertical riser, head tank, turbine intake, spiral case, wheel case, draft tube, discharge tank, suction header, and then back again into the pumps.

SIGMA

Sigma (σ) is the ratio of the barometric head (H_b) minus the static suction head (H_s) at any point, usually taken for convenience as the elevation of the blade pivot axis for Kaplan runners and the elevation of the runner discharge for Francis wheels, to the total operating head (H) on the turbine.

Critical sigma is determined in the laboratory by testing the model with a constant wicket gate opening (and blade angle in the case of a Kaplan turbine) at a constant speed under a constant head while the elevations of headwater and tailwater are lowered step by step for successive runs until a definite "break," or change in performance, is observed.

A 300-hp, 0 to 6000-rpm eddy-current dynamometer is used to measure the model horsepower output. A control console combines many of the controls and gages into a single unit. The butterfly valve located in the bottom of the vertical riser is controlled from the panel and adjusts the head by creating head loss and reducing flow.

This completely closed system has two centrifugal pumps which can be operated singly, in series, or in parallel to circulate water which has been fed into the system from the city water supply.

Figure 2 is a cross-sectional drawing of the head tank dynamometer, cylindrical barrel, and model turbine. The entire wheel case is suspended from the dynamometer frame and is mechanically independent of the head tank and other components of the pressurized system. The wheel case is attached to the cylindrical barrel which extends through the head tank but is connected to the tank merely by means of "music note" seals. With this mounting any breathing or other movement of the tank cannot affect the alignment of the turbine shaft. All rotating parts, including the turbine runner, shaft, and dynamometer rotor, are supported by a Kingsbury thrust bearing located in the top of the dynamometer stator.

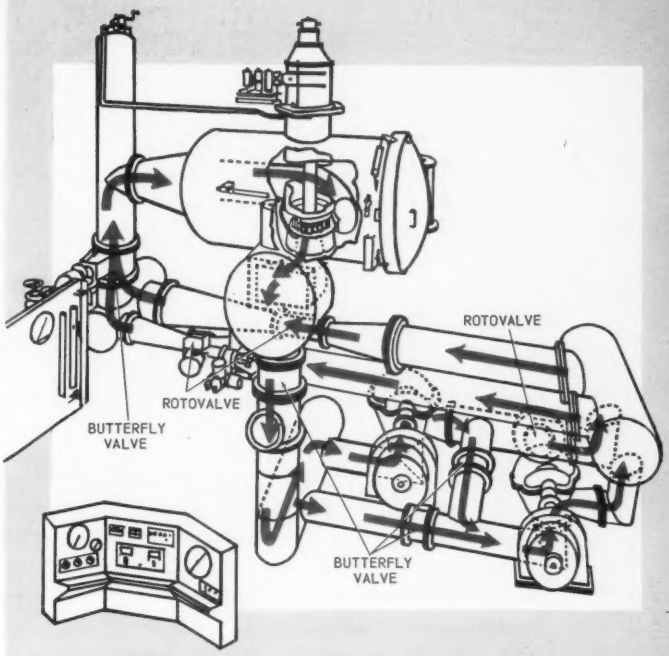
Figure 3 shows typical performance curves for three different heads with efficiency and discharges or cfs plotted against horsepower. The cavitation limit for each head is also shown in reference to various tailwater elevations. The curves were plotted directly from tests which were run in the high head test stand.

Figure 4 shows sigma break curves. These curves illustrate the accuracy and control attainable in the new test stand during a cavitation test. Curves are obtained for unit output, discharge, and efficiency versus sigma. Relative accuracy is possible even at very low sigma values. Critical sigma is indicated as a value corresponding to a loss in output of 1 percent, which is well within the output and efficiency margins normally maintained between "expected" and "guaranteed" performance of prototype units. In actual practice the prototype units are set according to test data of this kind with the exception that adjustments are made to include some safety. In other words, prototype units are set several feet lower than indicated by test results to insure smooth operation free from serious cavitation.

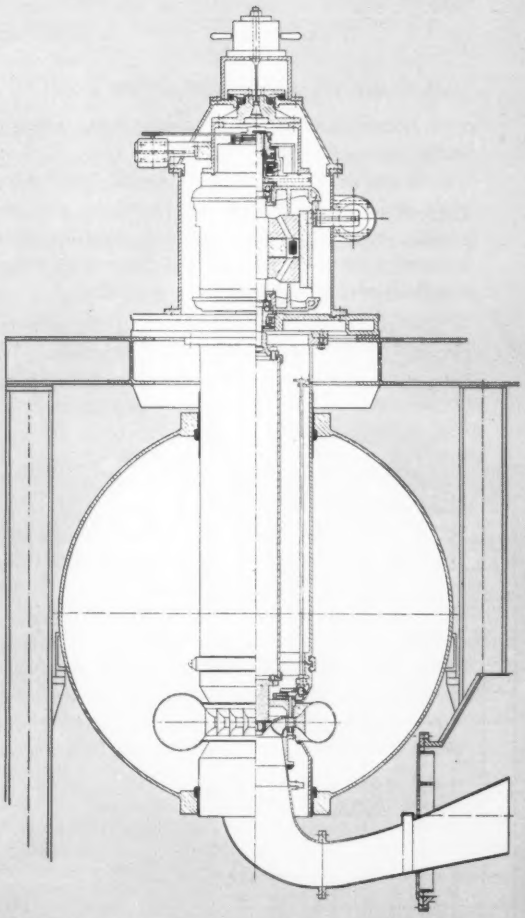
Hydro station modernized

In 1921 the City of Seattle installed two units in the Gorge Powerhouse, each rated 27,500 hp under a 275-ft net head when operating at 257 rpm. In addition to the 27,500 hp rating under the 275-ft net head, these units were designed to be capable of generating 37,500 hp at a future net head of 325 ft. In 1928 a third unit was installed in this powerhouse which was essentially a duplicate of the first two units. For the past 30 years all units have been operating under the 275-ft net head. Provisions were originally made for the present increase in the dam height to bring the net head up to 325 ft.

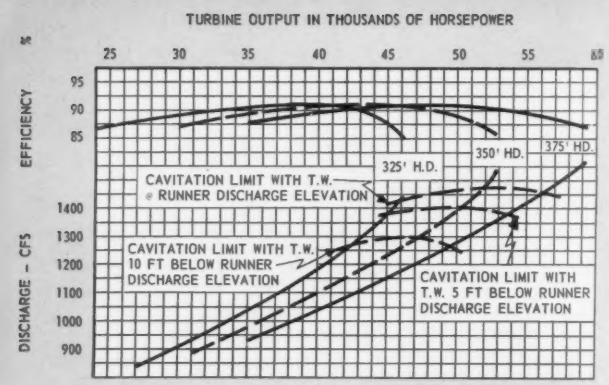
Because of the tremendous power demands in the Pacific Northwest, it was decided in 1955 to make the alteration to the dam for the increased head and also



DUPLICATION of field conditions for heads up to 300 feet is aim of test facility for determining power and efficiency over a range of unit speed (phi) as well as cavitation and runaway speed versus sigma on hydraulic turbine models. **(FIGURE 1)**



MODEL WHEEL CASE is suspended from the dynamometer frame and is mechanically independent of the head tank and other components of the pressurized system. Arrangement prevents misalignment and accompanying friction losses. **(FIGURE 2)**



TEST CURVES obtained directly from high head test stand show efficiency and cavitation limits. Output and discharge are stepped up to correspond to the prototype rating. **(FIGURE 3)**

attempt to obtain 45,000 hp at the 325-ft net head instead of the original 37,500 hp—a 20 percent increase in capacity. Good efficiency, 87.5 percent or over, with only minor alterations to the runner and wicket gate dimensions, was desired. The same inlet valves, spiral cases and draft tubes were to be used.

Cavitation was considered to be the greatest obstacle to a successful solution of this problem, since the runner discharge diameter and the plant operating sigma were essentially fixed at their installed values by the existing condition of the gate case and powerhouse. While achieving the desired increase in power would not prove too difficult, obtaining this increase efficiently and without serious cavitation, utilizing the same plant sigma, was another matter. To resolve this unknown, special tests were necessary, using a high head test stand.

A homologous model of the existing prototype unit, including runner, wheel case, spiral case, inlet valve, and a sufficient length of model penstock, was built. A complete series of tests were conducted on this model, including cavitation, efficiency and runaway speed. The laboratory tests established the base performance upon which increased performance was judged.

The problem was approached in increments of improved results, by testing two progressively improved runners in the homologous model of existing case-parts.

By building and testing a first-step runner model, corresponding to 42,500 hp at full gate on the prototype, a satisfactory runner design was available if the final-step runner proved impractical.

The final-step runner model was designed and built to correspond to 47,500 hp at full gate which is equivalent to 45,000 hp at 87.5 percent efficiency. Complete cavitation, efficiency and runaway speed tests were conducted on this model.

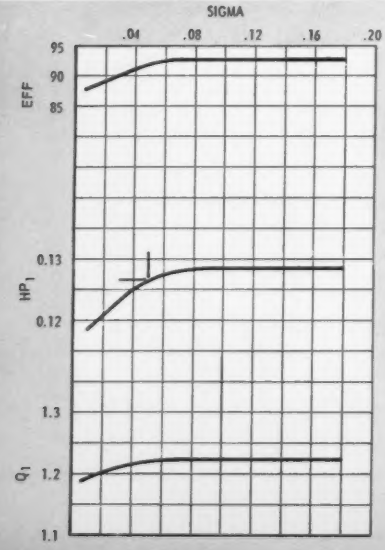
The performance curves in Figure 5 show that it was possible to obtain the desired 45,000 hp at good efficiency under 325-ft net head and without encountering signs of general cavitation.

Figure 5 shows performance curves of the original Gorge units and illustrates the comparison between the new high powered runner and the runner which is homologous to the existing units.

The new runner was supplied with stainless steel overlay to give the runner additional resistance against cavitation pitting. New redesigned gates required for the high powered runner provide a greater entrance area. As a result, velocities through the gates are approximately the same as on the original units. By maintaining the same velocities it is possible to maintain the same unit speed. A new gate mechanism was supplied to accommodate the new gates, and to conform with the design of the new runner, a new discharge ring was required.

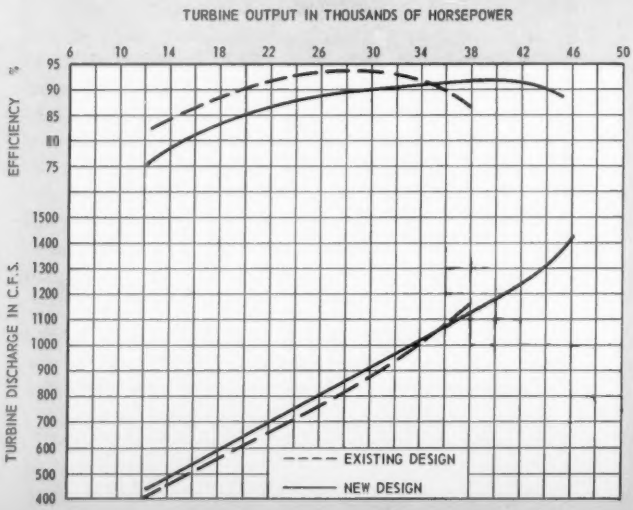
Because of the additional flow, the velocities in the spiral case are higher than standard practice would normally dictate. The tests which were conducted showed that good performance can be obtained with the higher velocities; however, some loss in efficiency must be expected.

In addition to the improvements which are possible with the Francis-type turbines, recent advances have also been made in the design of the axial-flow turbines. By incorporating these design changes into older axial-flow turbines, it is reasonable to expect that increased capacity can be obtained with relatively minor expenditures.



SIGMA BREAK curves obtained from test stand provide accurate performance data. **(FIGURE 4)**

FINAL STEP MODEL is compared with model homologous to existing unit. **(FIGURE 5)**



COMPUTERS *serve* POWER SYSTEMS

IBM 704 installation includes control console, card reader and printer. Tabulated information is taken from the printer in a standard typed format for ready reference and convenient study. **(FIGURE 1)**

by D. P. HARTMANN and M. A. SCHNETZLER
Engineering Analysis Section
Allis-Chalmers Mfg. Co.

The modern, high speed, large storage capacity digital computer is fast becoming a useful and economical tool for solution of high voltage transmission problems.

THE DIGITAL COMPUTER is contributing to the faster solution of increasingly complex transmission problems.

Great effort is continually being expended by high voltage transmission engineers to produce practical engineering solutions to various planning problems. Associated aspects of the problem solution from management's viewpoint must be included, and expert planning is often required to satisfy the demands of good engineering and sound financing.

Network problems become more complex

Engineering and economic planning methods used by transmission engineers are constantly undergoing experiment and change. Initially, electric power systems were small and radial; slide-rule and hand calculations were sufficient for solving operating and planning problems.

As systems grew, their complexity increased rapidly, especially because of the growth of loops and interconnected networks. The more complex systems demanded a much improved means of network solution.

There are 42 network calculator installations in operation in the United States. To the utility engineer, the network calculator is a tool which offers solutions to a wide variety of problems. Since the network calculator is a direct analog representation of the high voltage transmission system, the planning engineer can view a system in miniature, study the situation in detail, and make selected system changes while the study progresses. Thus a clearer understanding of the operating characteristics of a power system are obtained at a reasonable cost.

There are, however, certain limitations to the application of the network calculator for solution of transmission system problems. The network calculator is limited in size, with only a fixed number of components available at a given network calculator installation; therefore large systems, with their growing interconnected subsystems, cannot be represented in full detail.

Owing to rental costs and setup time of network calculators, many utilities use fixed schedule arrangements for their network calculator problems, which results in short, intensive spurts of calculator use. All studies must therefore be preplanned, and time is not available for extensive evaluation of results during the study period. Important new aspects arising during a study cannot be evaluated. There are resulting delays and costly setup time is lost when a system is repeatedly studied, as it must be because of the constant change and growth in customer loads. These considerations have led to the development of digital computer programs which can solve problems similar to those applicable to the network calculator, but with greater over-all economy and increased problem-solving ability.

There are various means, however, for overcoming some of the obstacles in computer usage and program development. Among the possible methods of achieving greater

program use is the establishing of a workable method of program exchange. Efforts to coordinate program development to eliminate costly duplication would also be extremely worthwhile. For this type of organized exchange, however, it is primarily important that the programs produced be sufficiently generalized to be profitably used by as many groups as possible. Many programs, such as load flow, fault calculations and transient stability, cover so wide a variety of power system conditions that the program development effort must be measured in terms of man-years and the costs in terms of tens of thousands of dollars.

For such large-scale programs a large staff would be necessary to fully investigate all the various aspects encountered in a given computer programming effort to insure production of a truly generalized and efficient program. Such a staff would enable efficient, economical production of programs for a wide variety of applications.

Digital solutions are timesaving

The convenience of digital computation can be demonstrated by a typical load flow solution. Input data requirements for digital load flow studies are similar to those for network calculator studies. Tabulated forms enable data preparation to be performed by clerical workers, thus freeing the engineer for more creative work.

These tabulated forms contain the problem data for the initial input. Data can be punched on IBM cards by a key punch operator without further supervision. The program and data can be loaded by the computer operator, and the results are automatically printed.

For the initial or base case digital computer runs, the utility engineer can be present at the computer if he desires, but his presence is not absolutely necessary. For secondary or additional load flow cases, the utility engineer can telephone, telegraph, or mail system changes for the new runs, since the required base case data can be stored at the computer. Subsequent runs can then be made whenever desired, and more important, these runs can be made quickly. By priority arrangement, it is possible to have load flows run and results returned on a same-day or same-week basis.

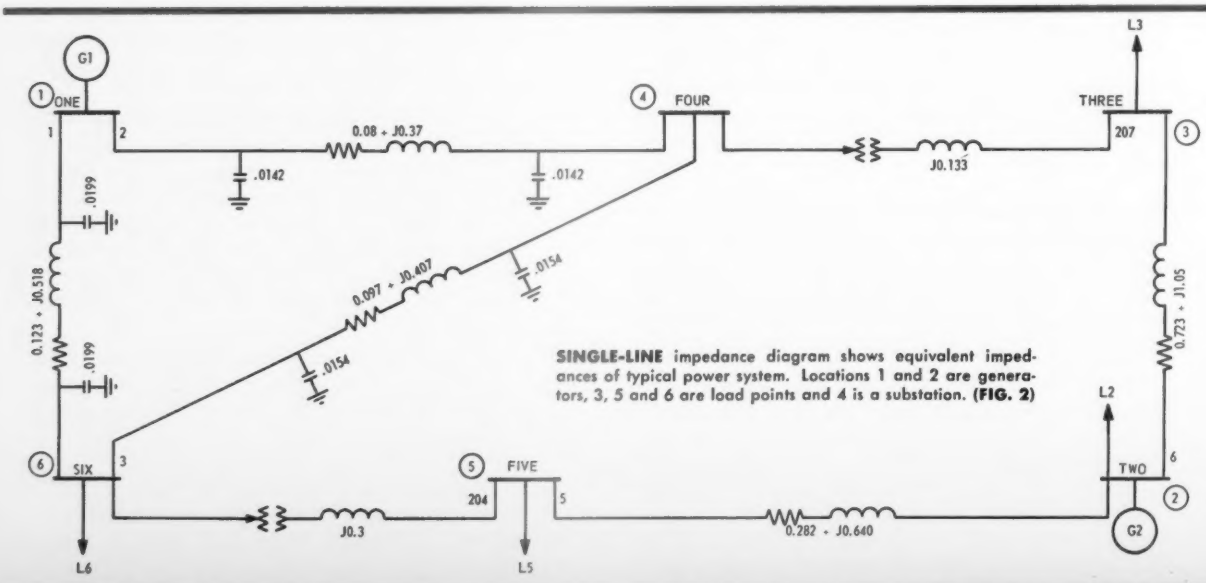
Since the data can be stored at the computer installation in suitable form for rapid input into the computer, setup time is minimized when studies are spaced. There is little chance for human error, since most data are handled by the computer. Likewise, the digital print-out is a permanent record which is free from human recording errors. Editing functions regarding current ratings and voltage limitations can be incorporated in the program. A list of line and transformer overcurrents and undesirable voltage levels can be had automatically. These editing functions are time saving, since they help the utility engineer toward faster data evaluation.

Computer scheduling, incorporating the requirements of modern utility management, is now on a demand basis. Among the problem possibilities are the short-circuit program, the transient-stability program and the program for the solution of economic dispatch equations.

Combined efforts produce optimum results

Many areas require time-consuming repetitious calculations to solve utility problems and new problem areas are presently under consideration for program development. These include digital computation for solution of regulator application problems, distribution transformer load management problems, and transmission line impedances. These are only a small portion of the many aspects of electric power transmission and distribution which can be investigated by digital means.

The utility engineer and the equipment design engineer both have valuable practical experience in many problem areas. However, without computer experience it is often difficult to arrive at a precise set of equations which will include all of the aspects of a given special problem needed in the formulation of a digital program. In this situation, utility and equipment design engineers can work together with the computer staff to develop a solution to their problem. A cooperative effort results in practical programs which produce economical and usable



SINGLE-LINE impedance diagram shows equivalent impedances of typical power system. Locations 1 and 2 are generators, 3, 5 and 6 are load points and 4 is a substation. **(FIG. 2)**

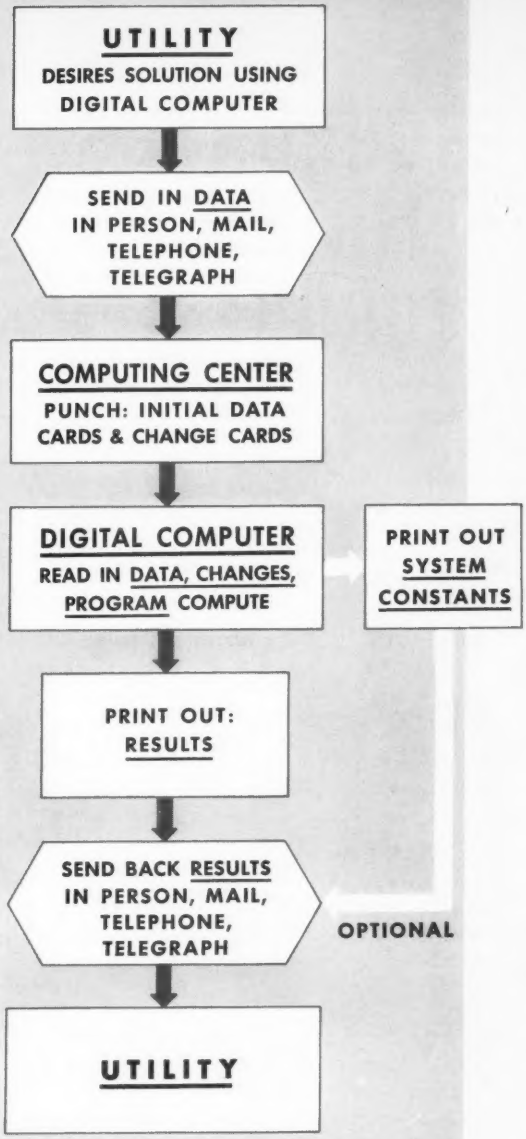
solutions. These solutions can be made available to others. Certainly an allied program development can do much to improve utility operating procedures by faster, more accurate solutions to operating and equipment design problems.

DIGITAL COMPUTER ADVANTAGES

1. High speed, repeatable series of calculations are easily obtained.
2. Human errors in data handling are minimized, since the computer itself does most of the data handling.
3. Quick data input minimizes time lost in setup.
4. No idle computer time is encountered; rental is based only on time actually used.
5. The central engineering analysis staff can include actual system conditions and analytical theory to provide practical and economical problem solutions.
6. Programmed computations can be readily applied to either the small or large-sized system without incurring additional programming cost.
7. Computer time is available on short notice.
8. Initial input data can be prepared by clerical workers.
9. Portions of the digital solution for a given problem can be edited by the computer itself.
10. Telephone, telegraph and mail data transfer is possible.

TYPICAL DIGITAL COMPUTER PROGRAMS

1. Solution of voltage regulator application problems.
2. Computations for selection of optimum placement of transmission line poles or towers for a given right-of-way profile.
3. Computations for production of charts showing service and entrance equipment needs for various loads and locations.
4. Solution of distribution transformer load management problems.
5. Computation of transmission line impedances for specified conductor configurations.
6. Solution of various equipment selection and placement problems.

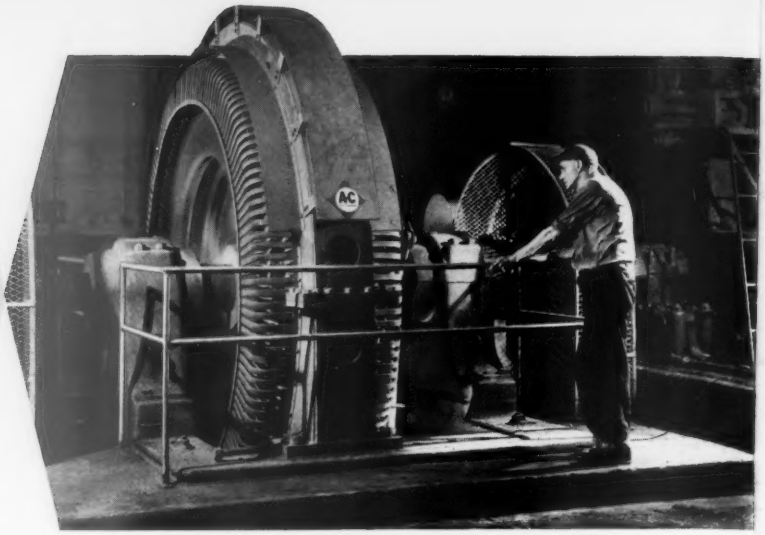

UTILITY
DESIRES SOLUTION USING DIGITAL COMPUTER
SEND IN DATA IN PERSON, MAIL, TELEPHONE, TELEGRAPH
COMPUTING CENTER
PUNCH: INITIAL DATA CARDS & CHANGE CARDS
DIGITAL COMPUTER
READ IN DATA, CHANGES, PROGRAM COMPUTE
PRINT OUT SYSTEM CONSTANTS
PRINT OUT: RESULTS
SEND BACK RESULTS IN PERSON, MAIL, TELEPHONE, TELEGRAPH
OPTIONAL
UTILITY

SYMBOLIC flow chart shows interchange of information between utility and computing center. Priority rating for computer problems assures prompt solutions. **(FIGURE 3)**

```
**BUS NO   6 HAS UNDERVOLTAGE   PERCENT VOLTS=  92.28   PERCENT MINIMUM VOLTS=  97.89   PERCENT UNDERVOLTAGE=   5.67

BUS NO   6   SIX      PERCENT VOLTS= 92.28  KVOLTS=127.35  ANGLE= -12.278
MW GEN=   0.      MVAR GEN=   0.      MW LOAD= -50.00   MVAR LOAD=  -5.00

  LINE NO.  NAME   MWATTS   MVARS   ACT. CURRENT  MWATT-LOSSES-MVAR  TAP
    101     ONE   -41.79  -10.16      195.0       2.626    11.056    0.

    103     FOUR   -9.28   -2.04       43.1       0.099     0.414    0.    PC OVLD=  7.7  AMPS=   43.1  MAX AMPS=   40.0

    204     FIVE    1.07    7.20       33.0      -0.        0.178   97.6

            MISMATCH   MW=  0.001   MVARS=  0.000


TOTAL SYSTEM VALUES
   GENERATION  MW =   180.17
   LOADING  MW =     170.00
   LOSSES
     GEN-LOAD MW=      10.17   MVARS=   25.47
     I SQUARE R(X) MW= 10.17   MVARS=   34.84
   ABSOLUTE MISMATCH MVA =   0.01
```

DIGITAL PRINT-OUT contains solution of load flow problem. Losses are calculated by I^2R method. The total system losses are automatically incorporated. **(FIGURE 4)**

SYNCHRONOUS MOTOR TORQUES DEFINED



HEAVY MACHINERY, such as pulp grinders in paper plants, presents torque problems that must be considered with six types of synchronous motor torques in mind. This 3000-hp synchronous motor is driving two pulp grinders at 225 rpm.

by R. C. MOORE
Motor-Generator Dept.
Allis-Chalmers Mfg. Co.

Torque definitions play important role when applying synchronous motors to modern drives.

SUCCESSFUL APPLICATION of polyphase synchronous motors requires torque and inertia information on both motor and load.

During the starting period when the motor is accelerating its connected load, both the torque developed by the motor and the torque required by the load vary. A typical motor speed-torque curve is compared to a load curve in Figure 1. The motor torque exceeds the load requirements at all speeds up to near synchronous speed. Load torque requirements during the acceleration of many types of drives may be predicted with practical accuracy. The load torque required during the acceleration of loads such as fans, certain types of pumps and centrifugal compressors, varies as the square of the speed. The load curve shown is typical of these loads.

Some types of drives, such as unloaded rubber mills and motor-generator sets, require little load torque during acceleration. However, attention must be given not only to the torque requirement but also to the inertia of the drive. A given motor may easily accelerate an unloaded centrifugal pump. The slow acceleration of the same motor applied to a high inertia drive, such as a sintering fan or chipper, may endanger the starting winding. Furthermore, with this type load the motor may not be able to "pull in" to synchronism.

Motor speed-torque curves do not follow such simple rules as fans or pumps, but may vary widely with changes in motor design parameters for certain drives. It may also be noted that speed-torque curves of synchronous motors resemble, in general, those of induction motors.

Synchronous motor starts like induction motor

Synchronous and induction motors have basically the same type of stator winding. In effect, the magnetic field of the stator winding is a series of consecutive north and south magnetic poles which rotate at a speed determined by the supply line frequency and the number of poles for which the stator winding is designed and wound. As line frequency is normally constant, the magnetic field rotates at a constant speed. When the rotor runs at less than the speed of the magnetic field, currents will be induced in the rotor amortisseur and field windings. The currents induced in the rotor windings are the source of motor torque during the acceleration of either a synchronous or induction motor.

A synchronous motor starts from rest and accelerates its load largely by means of the amortisseur winding embedded in the pole shoes. The field winding of the motor also influences the speed-torque characteristics, especially near synchronism. Normal practice is to short the field winding through a resistor during the starting period. A typical starting amortisseur construction, shown in Figure 2, resembles a squirrel-cage winding of an induction motor. The rods of the winding may be unevenly spaced and may vary in number, location, diameter and electrical conductivity. Such variations assist the designer in obtaining a suitable speed-torque curve for the load to be started.

Motor runs at synchronous speed

At synchronous speed the rotor does not slip with respect to the poles of the magnetic field of the stator winding. Since the rotor windings have no currents induced in them, they develop no torque. To develop motor torque at synchronous speed, the field windings are energized with direct current. As a result, each excited field coil produces a magnetic pole which locks in step with a pole of the magnetic field of the stator winding. With both stator and rotor poles magnetically locked together, the rotor rotates at the synchronous speed of the stator field at all times.

When the motor is loaded, a rotor pole simply shifts slightly backward in position with respect to a stator pole. In its new position, the rotor continues to operate at synchronous speed.

Types of torques are identified

Each of the three stages of motor operation from standstill to synchronous speed has associated with it various types of torques. For example, at standstill a motor develops "locked-rotor" torque or "starting torque." At full speed as a synchronous motor with excitation applied, the motor may be required to develop "pull-out" torque.

There are many torque terms used by motor designers and engineers in their study, analysis and application of synchronous motors. Some of the terms specified in motor applications may be subject to interpretation by various branches of the engineering profession engaged in designing, manufacturing, consulting and application services. To avoid confusion and misunderstanding in interpretation, authoritative definitions of widely used terms are desirable. Definitions are provided by the American Standards Association (ASA) in the "American Standard Definitions of Electrical Terms" and in the NEMA Motor and Generator Standards.

Torque terms commonly used in synchronous motor application, specifications and engineering literature are:

1. Rated-Load Torque
2. Locked-Rotor Torque
3. Accelerating Torque
4. Pull-In Torque
5. Reluctance Torque
6. Pull-Out Torque

Rated-load torque is basic torque

As defined in the ASA Standards: "The rated-load torque of a motor is the torque necessary to produce its rated horsepower at rated load speed." Rated-load torque, sometimes called full-load or normal torque, is often used as a basic torque reference to which other motor torque characteristics are compared. When used as a basic reference the numerical value of rated-load torque is considered to be 100 percent.

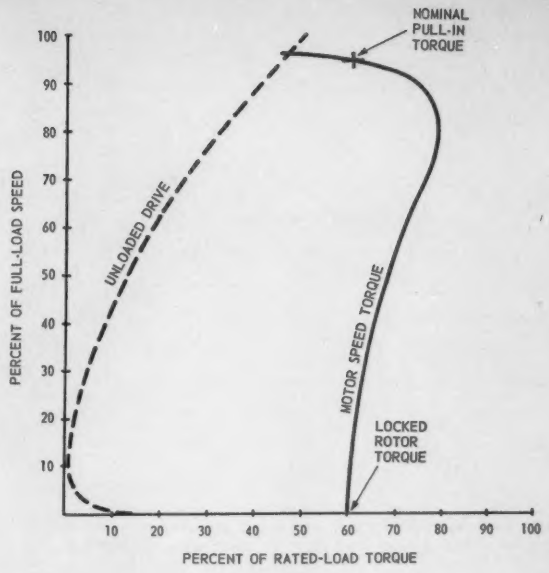
Locked-rotor torque occurs at standstill

As defined in the ASA Standards: "The locked-rotor torque of a motor is the minimum torque which it will develop at rest for all angular positions of the rotor, with rated voltage applied at rated frequency." Locked-rotor torque is sometimes referred to as starting torque and static torque.

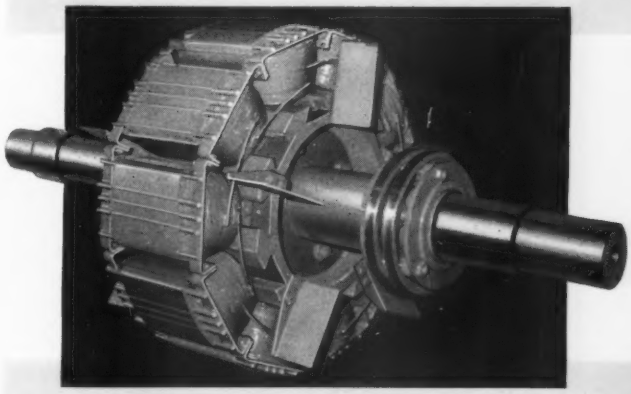
In addition to the torque produced by the amortisseur, a small amount of torque at rest is contributed by the field winding. During the starting and accelerating period of the motor and its connected load, the field winding is normally shorted through a resistor.

As expressed in the definition, the value of torque at rest is the minimum value which the motor will develop for all angular positions of the rotor. Some motors may exhibit variations in the locked-rotor torque at rest. These variations occur for different positions of the rotor with respect to the stator. In a well-designed motor the variations are not usually a large percentage of the average torque at rest.

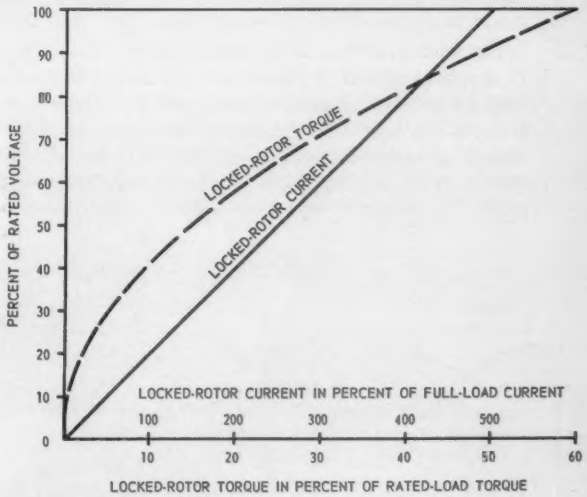
Variations in locked-rotor torque with terminal voltage changes are important considerations in the application



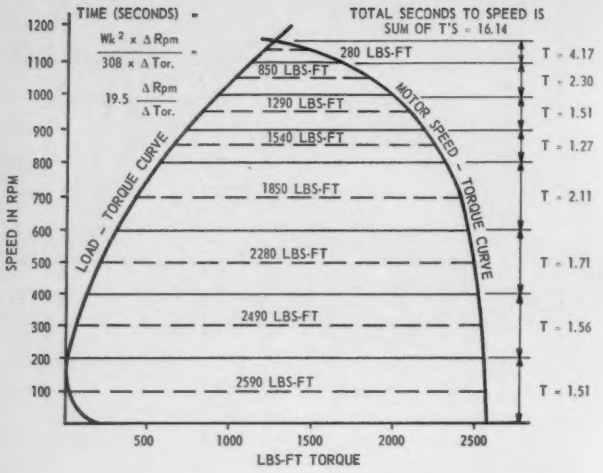
MOTOR TORQUE must exceed load torque at all points of motor and load curves to accelerate the load. **(FIGURE 1)**



AMORTISSEUR WINDING, consisting of short-circuited bars embedded in the pole face, provides most of the torque needed to accelerate a load. Rotor is for 600-hp motor. **(FIGURE 2)**



LOCKED-ROTOR torque and current are important factors in the selection of motors and their starting equipment. Voltage reduction decreases torque more than current. **(FIGURE 3)**



STEP-BY-STEP METHOD is used to calculate the time required to accelerate a load from rest to full speed. **(FIGURE 4)**

of motors. The curves in Figure 3 show that locked-rotor current taken by the motor varies directly with terminal voltage, and the locked-rotor torque varies as the square of the terminal voltage. At 90 percent of rated voltage, for example, the locked-rotor torque is 81 percent of the full-voltage value. Often saturation of the magnetic circuit results in the torque varying more than the square of the voltage.

Locked-rotor torque is often expressed in percent. The percentage value is then understood to be referred to the rated-load torque as the basic or 100 percent value. For example, a locked-rotor torque of 50 percent for a 600-hp, 1200-rpm motor is 50 percent of its rated-load torque. In pounds-feet the value is, therefore, 50 percent of 2626 or 1313 lb-ft locked-rotor torque.

Accelerating torque is a useful concept

The term "accelerating torque" occurs frequently in engineering literature. Although not defined in the standards, its meaning is generally understood by engineers. An example showing calculations, rather than a formal definition, may be used to illustrate the meaning and use of the term.

The curves shown in Figure 4 apply to a 600-hp, 1200-rpm synchronous motor and to a driven load whose torque varies as the square of the speed. The driven equipment is unloaded during start-up and requires only 50 percent of rated-load torque, or 1313 lb-ft, at full speed. Inertia of all rotating parts of motor and load is 6000 lb-ft^2.

The length of any of the horizontal parallel lines represents the torque difference between the motor developed torque and the load requirement. This difference torque, the motor excess over the load, acts to raise the speed of the rotating parts. The difference torque is, therefore, accelerating torque.

Accelerating torque may be used in the following formula to calculate the time required to change the speed of the inertia being acted on:

$$t \text{ (seconds)} = \frac{Wk^2 \times Rpm}{308 \times T}$$

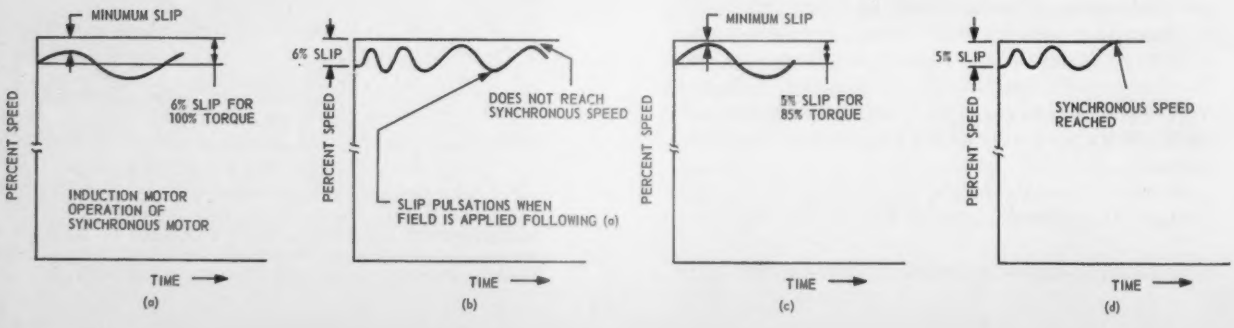
where Wk^2 = lb-ft^2 inertia of all rotating parts.
Rpm = speed change in revolutions per minute.
T = accelerating torque in lb-ft.

When the motor speed-torque curve closely parallels the load curve, as in Figure 1, it may be possible to estimate a single average value of accelerating torque, T, applying from rest to full speed. By using the formula, the time for the motor and its load to reach full speed from rest may then be determined by a single calculation.

Where the motor and load curves are not parallel, no single value or accelerating torque may be estimated with assurance that it would give correct starting time. However, starting time may be calculated using a step-by-step method, as shown in Figure 4.

A convenient speed range is assumed for the first step, during which the accelerating torque may be considered constant. In the example of Figure 4 the first speed range (first step) is chosen from 0 to 200 rpm. At the mid-speed location a dashed line represents the average net accelerating torque of 2590 lb-ft, which may be considered as constant over the 200-rpm speed range. Using the formula, the time in seconds for the motor and load combined inertias to reach 200 rpm is calculated to be 1.5 seconds. The next step assumes a speed change from 200 to 400 rpm, during which the accelerating torque of 2470 lb-ft, the dashed line mid-speed value, acts to raise the speed from 200 to 400 rpm. The time is calculated to be 1.56 seconds. Therefore, the time for the motor and its load to reach 400 rpm is 1.51 plus 1.56 or 3.07 seconds.

Successive similar calculations are shown in Figure 4. At the higher speeds, the speed range step is narrowed to 100 rpm to obtain a more accurate value of mid-speed accelerating torque. The complete time in seconds for the motor and load to accelerate from rest to full speed is indicated in the calculations of Figure 4. Greater accuracy can be obtained in calculating starting time by taking narrower speed steps.



Torque pulsations occur during induction-motor type operation

Operating at constant load a cage-type induction motor of uniform cage construction and magnetic circuit runs at a constant speed. Should cage dissymmetry occur, such as might result from broken bars, the nonuniform cage can be the source of torque pulsations and the motor will not run at constant speed.

Below synchronous speed, operating on its induction motor characteristics, a synchronous motor may also have torque pulsations caused by dissymmetries in the amortisseur starting winding, magnetic paths, etc. The pulsations may be more noticeable at low values of slip.

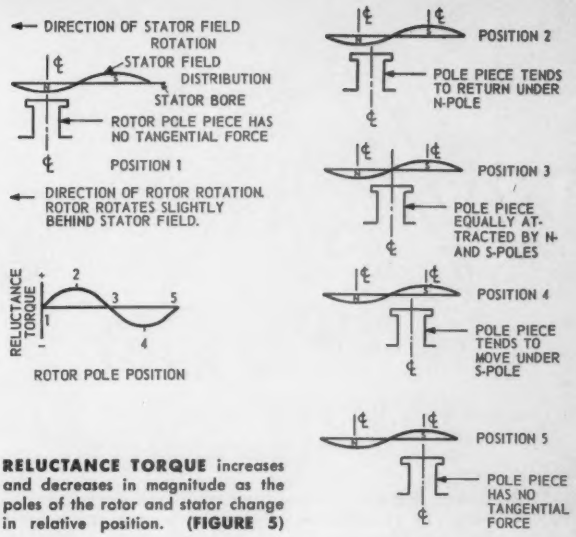
A very useful method of slip performance analysis of the synchronous motor is to consider two axes of symmetry on the rotor-symmetry with respect to the central radial axis of a rotor pole and also with respect to the central radial axis of the interpolar space. These axes may be referred to as the direct and quadrature axes, respectively. Equivalent circuits may be used to calculate direct and quadrature axes currents and torques. Because the two axes are dissimilar, the axes impedances, currents and torques, may be expected to be different. This difference between axes may be minimized by careful design. However, some torque differences between axes occur and torque pulsations result during slip cycles when a synchronous motor operates on its induction motor characteristics. The magnitude of the resulting speed pulsation is determined by the connected inertia.

Synchronous motor develops reluctance torque

Although not found in synchronous motor commercial specifications, "reluctance torque" is of interest because of its influence on motor pull-in and pull-out torques. The term is not defined in the standards.

Reluctance torque results from the saliency of the pole pieces of a synchronous motor, as shown in Figure 5. In position 1 an unexcited pole piece tends to take the position relative to the stator magnetic field so that the magnetic reluctance is minimum, that is, magnetic flux is maximum. In this position there is no force or torque on a rotor pole. If the rotor is shifted from position 1 to position 2 of Figure 5, a reluctance torque is developed which tends to return the rotor pole piece back to position 1. The reluctance torque variation is also plotted with respect to the pole position in Figure 5.

A salient-pole synchronous motor with unexcited field winding may, therefore, carry a small amount of load at synchronous speed as a result of reluctance torque. The rotor pole axis would then lag the stator pole axis. It is interesting to note that a wound-rotor type synchronous motor with uniform magnetic circuit and air gap does not develop a reluctance torque.

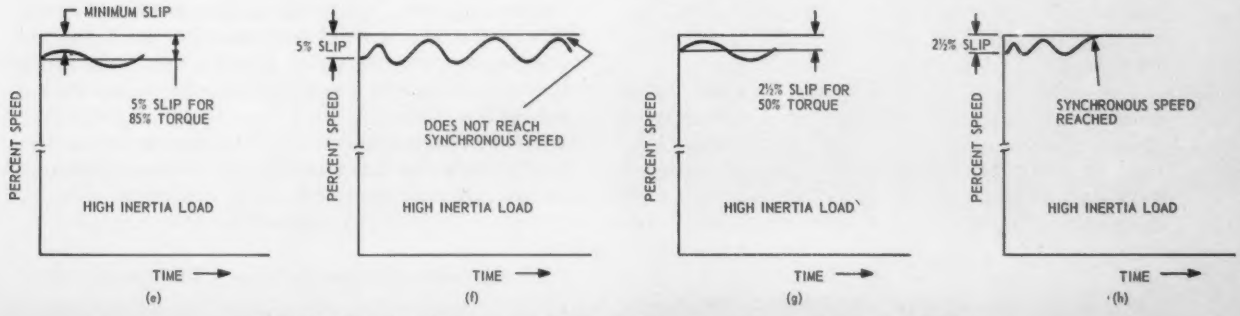

DIRECTION OF STATOR FIELD ROTATION
STATOR FIELD DISTRIBUTION
STATOR BORE
ROTOR POLE PIECE HAS NO TANGENTIAL FORCE
POSITION 1
DIRECTION OF ROTOR ROTATION. ROTOR ROTATES SLIGHTLY BEHIND STATOR FIELD.
RELUCTANCE TORQUE
ROTOR POLE POSITION
POSITION 2
POLE PIECE TENDS TO RETURN UNDER N-POLE
POSITION 3
POLE PIECE EQUALLY ATTRACTED BY N- AND S-POLES
POSITION 4
POLE PIECE TENDS TO MOVE UNDER S-POLE
POSITION 5
POLE PIECE HAS NO TANGENTIAL FORCE

RELUCTANCE TORQUE increases and decreases in magnitude as the poles of the rotor and stator change in relative position. **(FIGURE 5)**

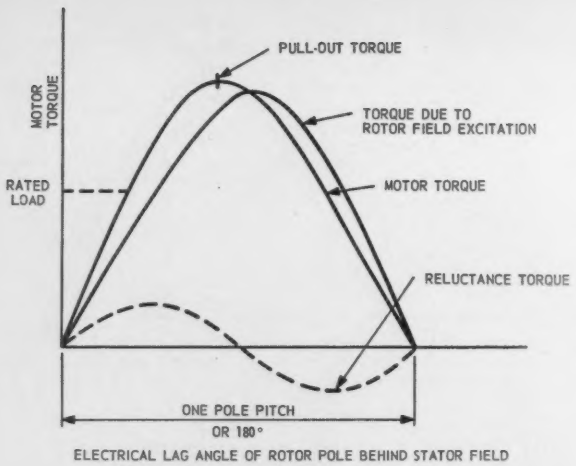
Reluctance torque effects may be further studied from Figure 5 for successive rotor pole positions relative to the stator field. At subsynchronous speed the net torque resulting from reluctance variations is zero. The torque variation effect does, however, introduce twice slip frequency speed variations at subsynchronous speed. The speed pulsations are usually not noticeable at low speeds because of the smoothing effect of motor and load inertias. Near synchronous speed, at low slip values, the twice slip frequency speed variations may be of larger amplitude.

Pull-in torque brings motor and load to synchronous speed

As defined in ASA and NEMA Standards: "The pull-in torque of a synchronous motor is the maximum constant torque under which the motor will pull its connected inertia load into synchronism at rated voltage and frequency, when its field excitation is applied." The standards also state that the "speed to which a motor will bring its load depends on the power required to drive it, and whether the motor can pull the load into step from this speed depends on the inertia of the revolving parts, so that the pull-in torque cannot be determined without having the inertia value as well as the torque of the load."



SLIP ANGLE and load inertia determine if a machine will pull into synchronism. **(FIGURE 6)**



PULL-OUT TORQUE is the maximum value of synchronous torque developed by a synchronous motor. This value is determined largely by field strength and the value of reluctance torque. **(FIGURE 7)**

During pull-in a synchronous motor changes from induction to synchronous operation. Just prior to pull-in the influence of induction motor operation is of interest and importance. As shown in Figure 1, a synchronous motor operates from standstill up to a top speed where its induction motor torque equals the required load torque. The motor speed will increase no further in normal applications. As previously pointed out, the top speed reached will not be a steady speed. Variations in motor slip may occur as shown in Figure *6a*, where the average slip is 6 percent. The value of minimum slip, that is, maximum speed, has an important bearing on motor pull-in when field excitation is applied.

The graph of Figure *6a* illustrates the induction motor slip cycle at full speed as the motor slips slowly backward with respect to the synchronously rotating stator magnetic field. The slip cycle is assumed to apply for a given connected inertia load and a constant torque load of 100 percent at 6 percent average slip. Field excitation may now be applied.

It is obvious that field excitation may be applied for any position existing between positions 1 and 5 of Figure 5. In some positions magnetic field flux build-up caused by excitation may add to the flux already trapped in a favorable reluctance position. Or the reverse may be true, that the field flux build-up resulting from excitation will "buck" down the trapped flux. The former situation may be expected to be more favorable than the latter for pulling in the rotor to synchronism. Optimum and worst "switching angles" therefore exist. The optimum switching angle provides the highest pull-in torque capability. Since the pull-in torque definition does not mention switching angle, it may be presumed that the worst angle must be allowed for to assure pull-in.

The curve of Figure *6b* indicates that field current build-up alters magnetic conditions and introduces an additional torque which produces wider speed swings. However, the motor may not pull in 100 percent torque. By reducing the load torque, as shown in Figure *6c*, a maximum value of, say, 85 percent torque may be found under which the motor pulls in its connected inertia load into synchronism, as shown in Figure *6d*. By definition, the pull-in torque is 85 percent.

If the same motor is connected to a higher inertia load, it may be found that the motor no longer will pull in at 85 percent load torque. The higher inertia smoothes out the slip swings, as shown in Figure *6e*. The speed gap to synchronism may not be spanned and pull-in may not occur when field excitation is applied. However, if the load torque is reduced from 85 percent to 50 percent, as shown in Figure *6g*, the average induction motor speed increases and the motor speed during slip cycle swings approaches synchronous speed more closely. Upon application of field the motor may then pull into synchronism, as shown in Figure *6b*. If 50 percent load torque is the maximum value the motor can pull in, then the motor has 50 percent pull-in torque by definition.

Nominal pull-in torque is defined

As defined in the standards: "The nominal pull-in torque of a synchronous motor is the torque it develops as an induction motor when operating at 95 percent of synchronous speed with rated voltage applied at rated frequency." A further note explains that "this quantity is useful for comparative purposes when the inertia of the load is not known."

Nominal pull-in torque depends solely on the induction motor characteristics of a synchronous motor at 95 percent speed, as shown in Figure 1.

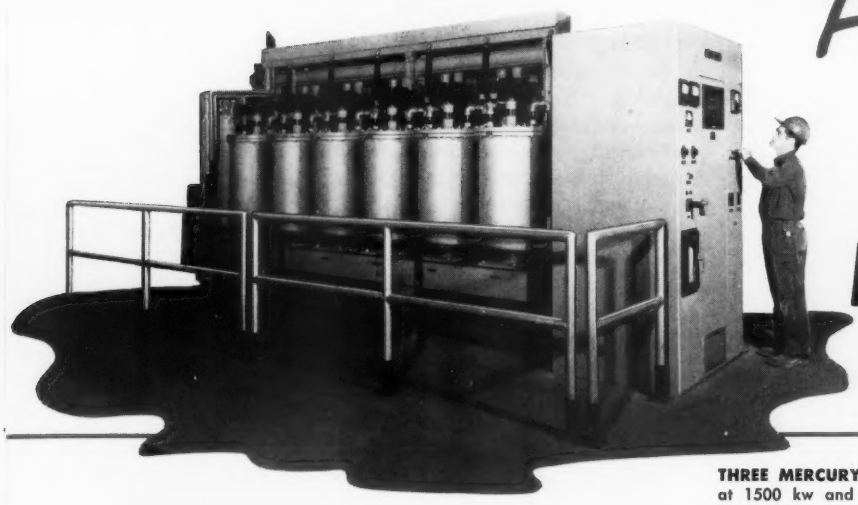
Pull-out torque indicates maximum load capability

As defined in the standards: "The pull-out torque of a synchronous motor is the maximum sustained torque which the motor will develop at synchronous speed with rated voltage applied at rated frequency and with normal excitation."

After accelerating on its induction motor characteristics and pulling the inertia load into step, a synchronous motor operates on its synchronous characteristics exclusively. As previously mentioned, the motor will carry a small load at synchronous speed without excitation because of reluctance torque. When field excitation is applied the rotor poles become magnetized with definite polarity, thereby greatly increasing the load torque capability of the motor. The combined torque effects of reluctance and field excitation, shown in Figure 7, are sometimes referred to as "synchronous torque," the maximum value of which is the pull-out torque indicated. It may be noted that rated-load torque operation is well within the pull-in torque capability of a synchronous motor. Typical pull-out torque values are 150 percent rated-load torque for 100 percent power-factor motors and 175 percent rated-load torque for 80 percent power-factor motors. Pull-out torque of a synchronous motor is proportional to the motor terminal voltage, as contrasted to induction motors, for which breakdown-torque is proportional to the square of the voltage.

Whenever synchronous motor torque terms appear in specifications and literature, a correct interpretation of terminology will assure successful application of these motors.

Automatic Degassing... of MERCURY-ARC RECTIFIERS



THREE MERCURY-ARC RECTIFIER units and control cubicles, rated at 1500 kw and 250 volts each, power wire-drawing machines in steel plant. Installation provides for future growth. **(FIGURE 1)**

by L. E. NICKELS
Rectifier Section
Allis-Chalmers Mfg. Co.

Much time and effort are saved when pumped-tube rectifiers are degassed automatically.

PUMPED-TUBE MERCURY-ARC RECTIFIERS are automatically degassed to achieve their required high degree of vacuum. Rectifier load current raises the temperature of the elements to drive off the occluded gases. A vacuum pumping system operating continuously maintains the tube vacuum during the degassing cycle.

Load current varies automatically according to a prescribed degassing schedule without exceeding vacuum limits. In case of system faults, the rectifier will drop its load current until the fault is manually corrected and the unit put back into operation. A typical pump-evacuated rectifier is shown in Figure 1 and the automatic degassing control cubicle is shown in Figure 2. Normally a frame of two, six, or twelve tubes can be degassed simultaneously.

Heat generated to drive out the occluded gases in the tube elements is produced by rectifier load current passing through main arc from anode to cathode. Heat is controlled by varying the rectifier load current. The tubes are connected to the rectifier transformer secondary, with a phase-to-neutral voltage of approximately 40 volts present across each rectifier tube. The load current is controlled by varying the angular displacement between anode voltage and grid voltage. With maximum angular displacement the rectifier will carry no load, and as the displacement is decreased, the load current will increase. Therefore, advancing the grids increases load current and retarding the grids decreases load current. Change in grid position is initiated by the pinwheel circuit in Figure 3. A complete rectifier degassing circuit is shown in Figure 4.

Manual degassing needs constant attention

To degas a tube manually, sufficient load current is picked up to produce a vacuum of approximately 3.0 to 3.5 microns, as measured by a McLeod gage. As the vacuum decreases, the current is manually increased by grid control until the initial pressure of 3.0 to 3.5 microns is reached. If the vacuum goes above the initial values, the pressure is reduced by decreasing the load current. The rectifier load current must be adjusted continually to maintain the vacuum as close as possible to 3.0 microns. Good degassing requires the almost constant attention of two operators 24 hours per day until the operation is complete. The degassing process is finished when the rectifier tubes can carry rated load current at a pressure of less than 0.7 microns. A final leakage test is made to check vacuum tightness of the tubes.

DEGASSING CONTROL CUBICLE contains contact-making vacuum meter, annunciator, recording ammeter, and controls for setting up the operating sequence. Operation is then automatic. **(FIGURE 2)**

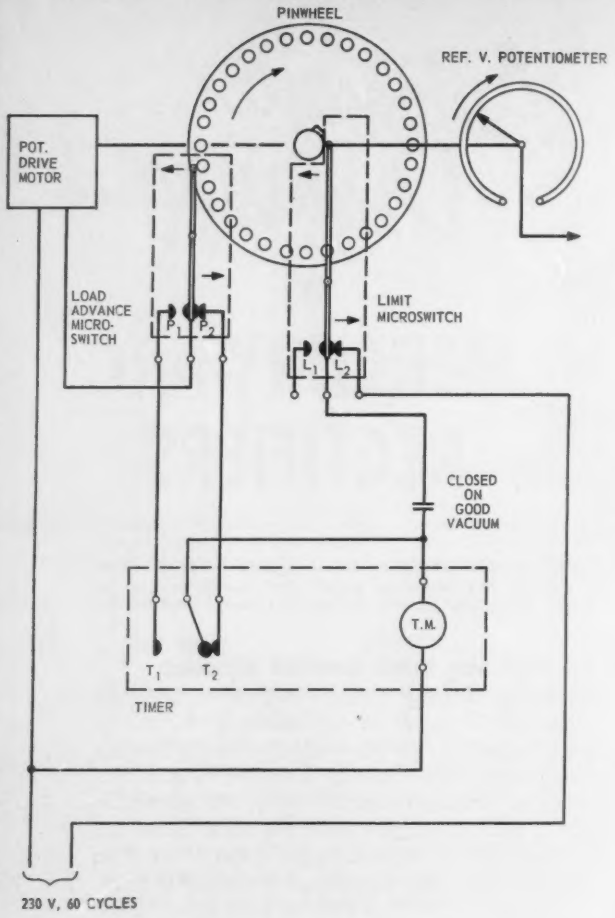


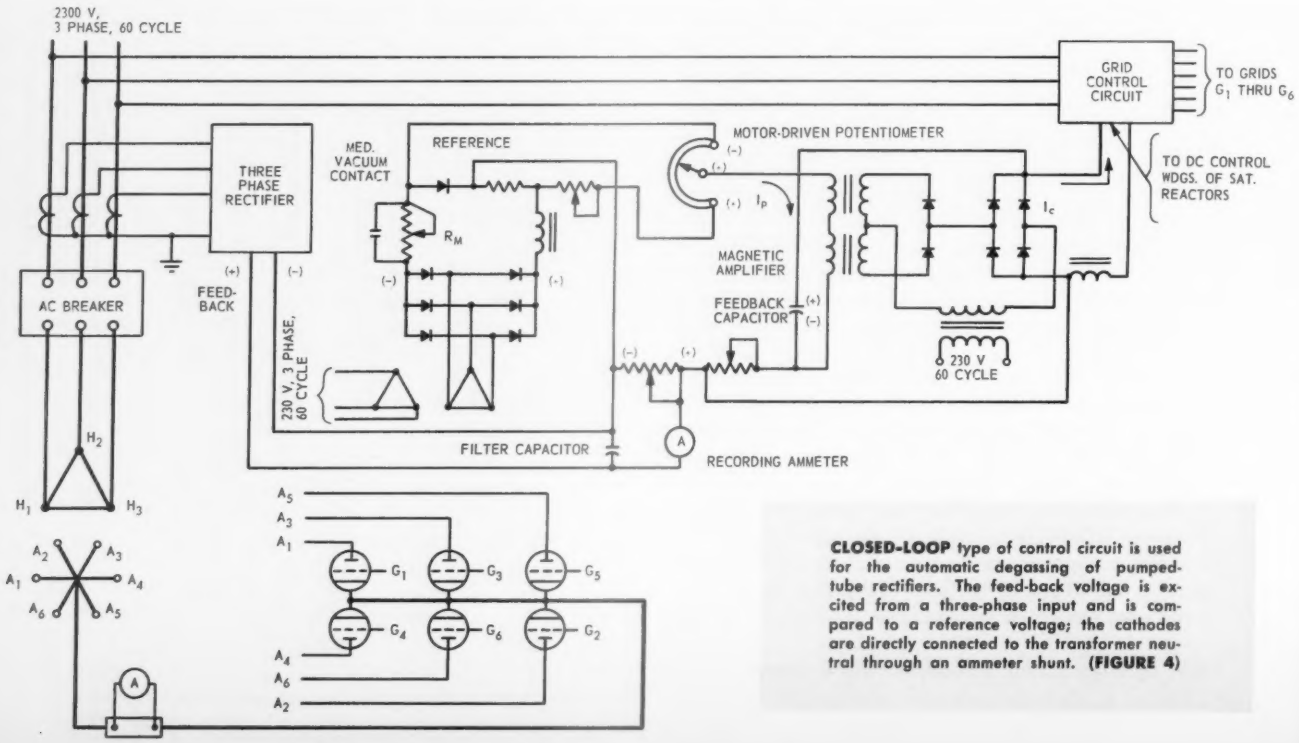
DIAGRAM shows the motor-driven pinwheel that actuates automatic degassing cycle. Sequence switches set operating mode. **(FIGURE 3)**

Tubes are degassed unattended

A pumped-tube rectifier is automatically degassed by controlling the angular displacement between the anode voltage and grid voltage to control the load current. Changing the dc control current through the control windings of a saturable reactor in the grid control circuit varies the angular displacement of grid voltage with respect to the anode voltage. An increase in control current advances the phase angle of the grid voltage which increases the rectifier load current; a decrease in control current retards the phase angle of the grid voltage which decreases the load current. The automatic controls vary the dc control current and thereby the rectifier load current.

A feed-back voltage from a rectified dc supply, excited from the three-phase input, and a dc reference voltage from a separate dc supply are nearly equal in amplitude and are opposite in polarity. Since the reference voltage is slightly less than the feed-back voltage, a current of only a few milliamperes will flow through the magnetic-amplifier control windings. The relationship of magnetic-amplifier control current (I_p) and the dc control current (I_c) of the saturable reactors (magnetic-amplifier secondary) is illustrated in Figure 5.

A change in reference voltage will cause rectifier load current to change until feed-back voltage from the current transformers is nearly equal to the new reference voltage level. The reference voltage and the rectifier load current are automatically increased and decreased proportionally with each other. Any change in load current, either intentionally made or initiated by a timing sequence during the degassing operation, results from an automatic change in the reference voltage. Reference voltage is supplied by a motor-driven potentiometer, automatically controlled by a vacuum meter, timer and pinwheel, shown in Figure 6.



CLOSED-LOOP type of control circuit is used for the automatic degassing of pumped-tube rectifiers. The feed-back voltage is excited from a three-phase input and is compared to a reference voltage; the cathodes are directly connected to the transformer neutral through an ammeter shunt. **(FIGURE 4)**

Operation samples vacuum condition

Successful automatic degassing depends largely on proper operation of the contact-making vacuum meter. The vacuum meter operates three separate contacts that set up a desired operating sequence. The meter causes the rectifier vacuum to be sampled by a hot wire measurement once each minute. During sampling, the meter may close any one of its three preset contacts: one will close at pressures less than 3.5 microns ("good" contact), another between 3.5 and 7.0 microns ("medium" contact), and the third at values greater than 7.0 microns ("bad" contact). When the vacuum is "good," the automatic control causes the timer to change the reference voltage a preset amount every half hour up to rated value. Operation will continue as long as the contact-making vacuum meter continues to close the "good" contact at the rate of once per minute.

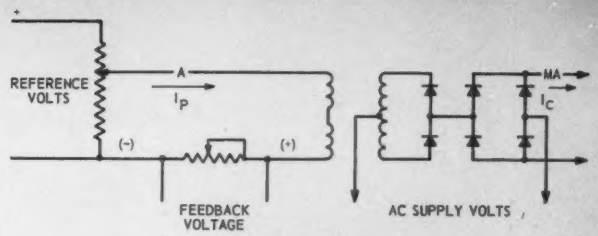
If the vacuum condition should cause the "medium" contact to close, the timer will stop running. Since there is a resistor (R_M) in the voltage reference circuit, the reference voltage decreases a measured amount. The reduced rectifier load current will allow a more rapid return of the rectifier tube vacuum to less than 3.5 microns. The timer will resume running when the "good" contact is reclosed.

If ever the "bad" contact should close, the rectifier is de-energized until vacuum conditions permit the "good" contact to close and allow the tubes to resume carrying the same load current that was carried prior to the shutdown.

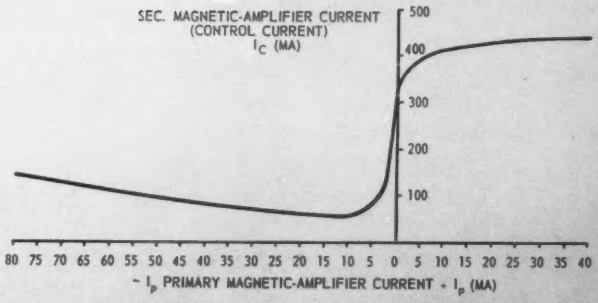
Protection against high cooling water temperature, low water pressure, poor vacuum, low line voltage and prolonged excitation failures is incorporated in the automatic control system. A fault resulting from any one of these will de-energize the rectifier, give an annunciator indication and sound an alarm. The equipment will remain de-energized until an operator arrives to correct the fault and place the rectifier back into operation. Shutdowns of this type are extremely rare and are usually not experienced throughout the entire degassing operation. Degassing a group of frames automatically takes only slightly more time than for a single frame. A maximum of 8 man-hours is required to connect and disconnect a 12-tube frame to an automatic degassing station, whereas approximately 240 man-hours are required to degas the same frame manually.

Appreciable savings can be realized when large numbers of pumped-tube rectifiers are automatically degassed. The process also reduces initial cost of pumped-tube rectifiers.

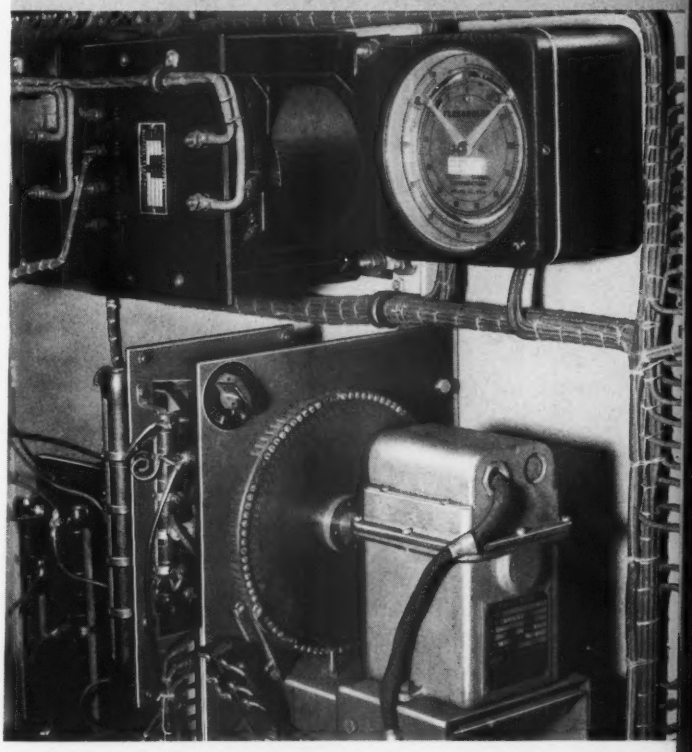
Pumped-tube rectifiers are furnishing reliable dc power for many important industries. Their principal advantages are static operation, dependable output and long service life. Users requiring equipment with these inherent characteristics, such as metal and chemical processing industries, prefer mercury-arc rectifiers as a flexible, reliable source of dc power.



SIMPLIFIED MAGNETIC-AMPLIFIER CIRCUIT


SEC. MAGNETIC-AMPLIFIER CURRENT (CONTROL CURRENT) I_C (MA)
500
400
300
200
100
80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0 5 10 15 20 25 30 35 40
- I_p PRIMARY MAGNETIC-AMPLIFIER CURRENT + I_p (MA)

CHARACTERISTICS of typical single-phase magnetic-amplifier control circuit for the automatic degassing system are illustrated. **(FIGURE 5)**

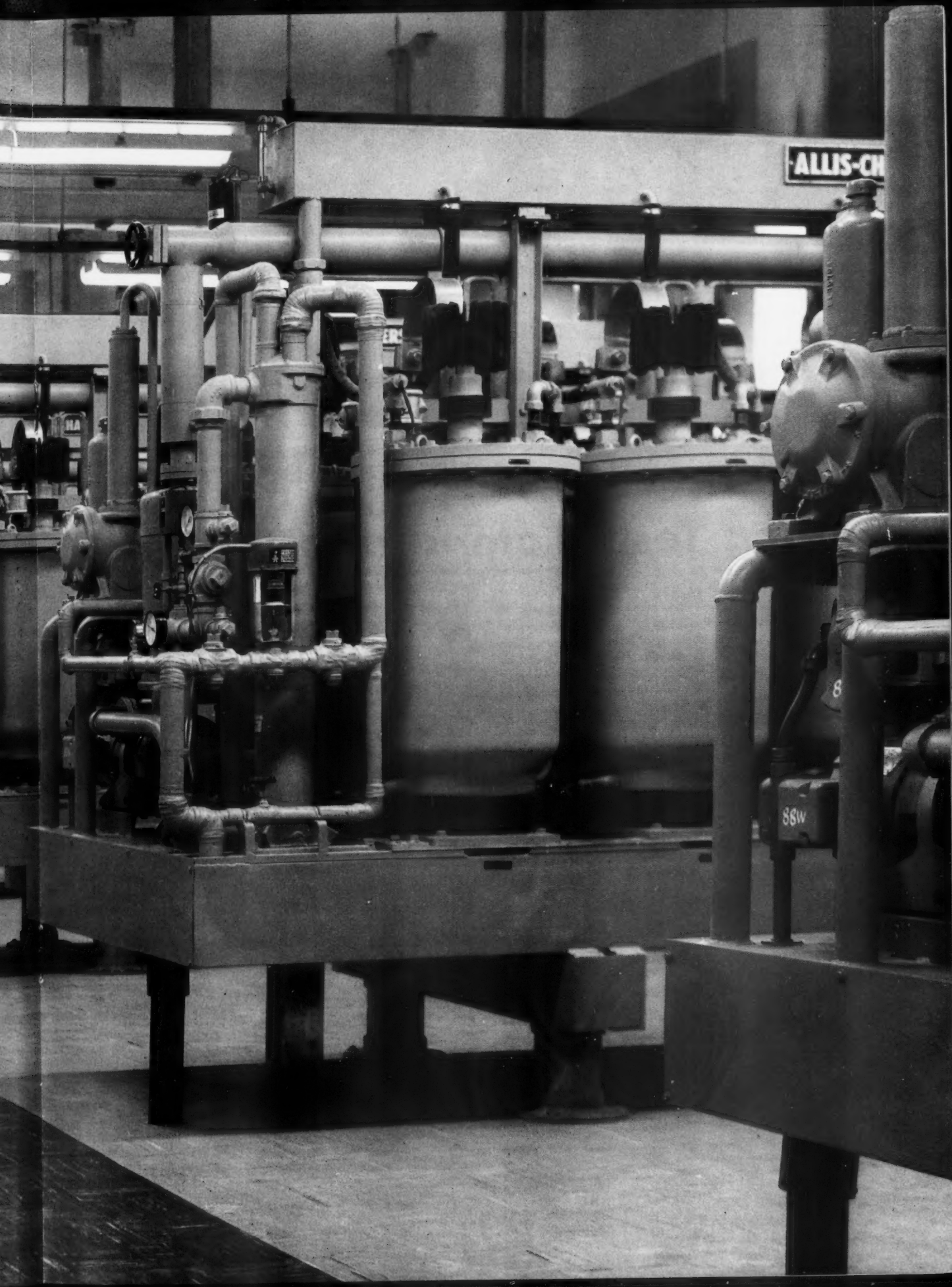


TIMER ACTUATES a motor-driven pinwheel and microswitch to provide uniform spacing of the potentiometer arm that sets the reference voltage level. Second microswitch prevents the potentiometer from allowing more than rated rectifier tube load current. **(FIGURE 6)**

THIRTY-TWO OF THE 48 mercury-arc rectifier frames just installed at Reynolds Metals Company's aluminum reduction plant at Massena, N. Y., are shown. These units supply two of the three potlines, each rated 80,000 amperes, 850 volts dc.

The rectifiers are the 12-tube pump-evacuated *Excitron* type, nominally rated 5000 amperes per tube. Each frame includes a water-to-water heat exchanger, water and vacuum pumps, anode-balancing reactors, and the combination return header and expansion tank. Each aluminum twin control cubicle at left supplies auxiliary power and excitation control to two rectifier frames.

Allis-Chalmers Staff Photo by Harold Shrode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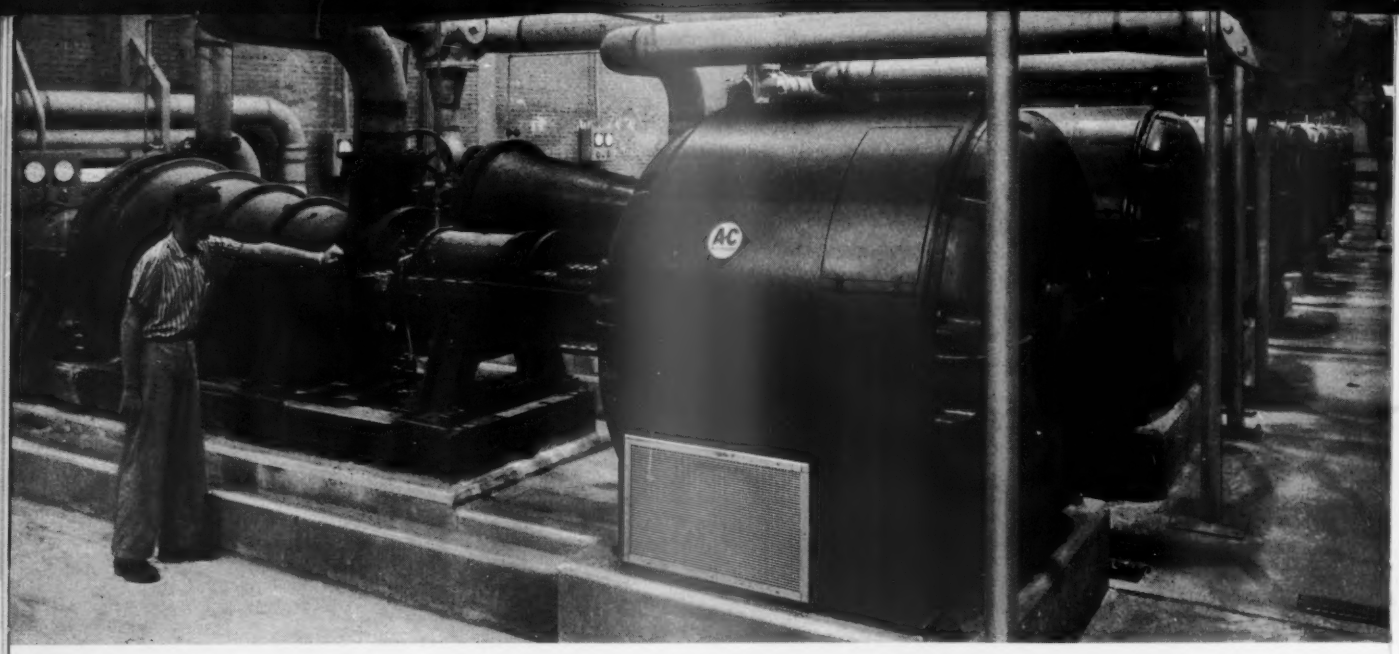


SYNCHRONOUS MOTORS, rated 400 hp, 2300 volts, three-phase at 400 rpm, drive processing machinery in a large paper plant. Severely humid condition has no effect on the silicone-rubber insulation.

Aging Tests Compare Insulation

by P. Q. NELSON
Apparatus Engineer
Southern California Edison Co.
and
R. J. POTTS
Motor and Generator Dept.
Allis-Chalmers Mfg. Co.

Destructive tests for insulation systems compare Class A and B insulations with silicone-rubber insulation.

CLASSIFICATION of newer insulation systems according to temperature limits by tests rather than by chemical composition has been gaining recognition and support in recent years.

AIEE Insulation Committees have developed several test codes and procedures for conducting insulation tests and analyzing the results. These tests suggest a series of exposures to heat, vibration, moisture and voltage stress to which the test samples or models would be subjected in repeated cycles.

Test exposures are designed to represent cumulative effects of service and necessarily represent accelerated aging conditions. The number of test cycles and the total number of hours of heat aging that the average of the test sample groups endured to the end life of the insulation are reported as test results. The end life of the coils was established by their failure to withstand voltage stress.

Test requirements are severe

A series of accelerated aging tests on a group of 2300-volt insulated motor coils was performed by the Southern California Edison Company. The coils employed Class A, Class B and Class H insulating systems. The Class H coils were arranged as an all-silicone-rubber ground insulation system. One of the principal test objectives was to determine the ability of silicone rubber, as a motor insulation, to retain initial dielectric strength, moisture resistance and physical characteristics after exposure to repetitive cycles of accelerated heat, moisture, mechanical stresses and voltage stresses. As a result silicone rubber can be compared to earlier types of insulation and an estimate made of relative service life.

Three groups of three typical 2300-volt coils were used in the tests. The coils were form-wound, multi-turn and single path wound coils. The test program consisted of subjecting the coil samples to a sequence of accelerated temperatures, voltage stress, mechanical stress, water immersion and voltage checks or until failure of the individual coils during voltage tests.

Temperature

All coil specimens were placed in the preheated, ventilated electric oven enclosure shown in Figure 1. The test temperature at the start of the comparison was selected for the

Class A coils, which had the lowest insulation temperature classification. The higher temperature Class B and Class H coils were also subjected to this initial test temperature. After the Class A coils failed, the higher Class B and Class H temperatures were applied. Temperatures varied from 160 C to 280 C in four steps and each exposure lasted for 96 hours. The coils were protected from direct radiation of the oven heating element and temperatures were periodically checked during the test.

Voltage application

Immediately after the coils were removed from the oven, and before they had cooled, 5600 volts at 60 cycles were applied for one minute between the coil conductors and an aluminum foil electrode, which was wrapped tightly over the entire slot section and out about ½ inch on the coil end. The voltage was applied to each coil side independently, as shown in Figure 2.

Mechanical stress exposure

Following the voltage test, the coils were subjected to a 20-cps oscillating motion with a peak-to-peak amplitude of approximately 12 mils for one hour. These vibrations are considered to be more severe than those occurring in actual service.

Moisture exposure

The coils were exposed to an atmosphere of 100 percent relative humidity at 37.8 C for 48 hours after each cycle of thermal aging and mechanical stress and then placed in the humidity chamber to permit cover condensation to drip directly on them. After several test cycles a complete water immersion for ½ hour was substituted for the humidity chamber exposure. This change was made because it appeared that humidity exposure was not severe enough to provide the searching effect desired to indicate incipient failure.

Voltage applications

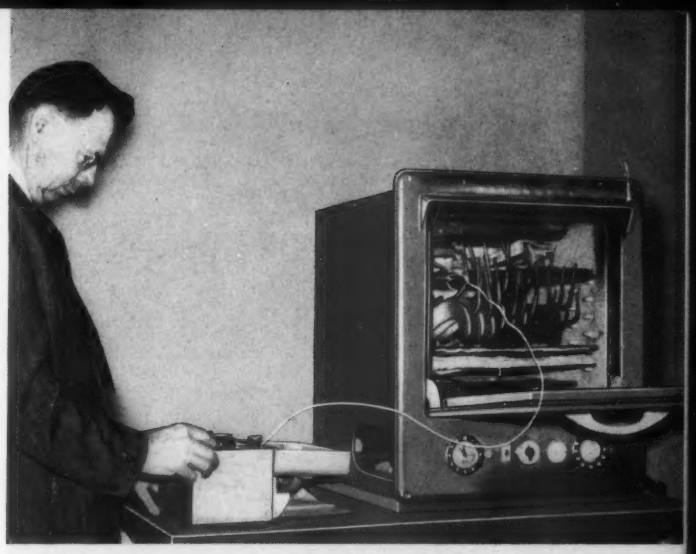
Immediately after the moisture exposure test, a 60-cycle line-to-ground voltage of 3000 volts was applied to each wet coil, as in the voltage test, for 10 minutes. If a flashover or excessive leakage current occurred, the particular coil was considered a failure.

Test evaluation

The number of cycles of test exposures required to deteriorate the insulation to failure on voltage application constituted the final results of the aging tests. Visual observations of the physical conditions of the coils were a further indication of failure. Since test procedures were intentionally more severe than general service conditions, test results permit comparisons of types and not service life expectancy.

Tests arrive at insulation comparison

The general conclusion is that mechanical stress, moisture exposure, and voltage stress will not adversely affect a well-designed insulation system unless the chemical and deteriorating effects of aging have appreciably reduced the physical strength of the coil. This aging effect, such as characterized by oxidation, chemical changes in molecular composition, hardening or embrittlement, cracking,



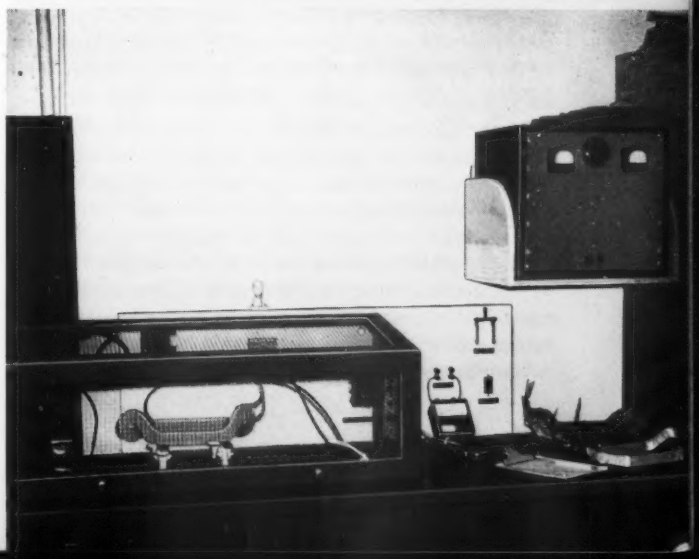
MOTOR COILS were first subjected to thermal aging in a preheated, electric oven. After an exposure to the initial test temperature, each coil passed through the test sequence. Successive cycles determined the final results of the accelerated aging. **(FIGURE 1)**

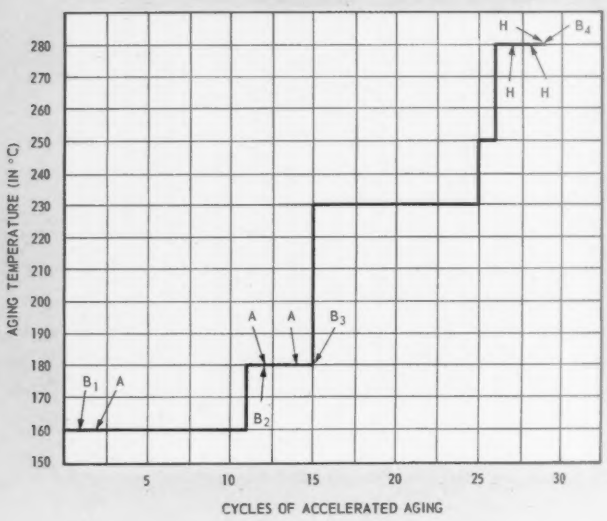
will be accelerated by heat. In the testing program, the oven aging portion of the cycle served to accelerate the aging effect, and the other exposures located or established the failure point.

The test data for the three groups of motor coils were plotted as successful aging cycles without voltage failure versus aging temperatures, as in Figure 3. All coils were oven aged as a group at the lowest temperature of 160 C until approximately 11 cycles had been completed, though the temperatures used were based on a test life expectancy of about 10 cycles. A further consideration was the approximate 10-degree rule for insulation deterioration which states that insulation life is reduced by one-half for every 10 C temperature increase.

Explanatory notes in Figure 3 give a brief summary of the results of the aging tests. The Class A coils had been well insulated and had a good varnish treatment. Were it not for the quality construction, complete failure would probably have occurred on the Class A coils before the

AIEE TEST VOLTAGE was applied to each wet coil immediately after the moisture exposure. This was the crucial test. **(FIGURE 2)**





EXPLANATION

A — Class "A" coils failed during 3000 volt test after 30 minutes immersion.

B_1 — After 1st cycle all Class "B" coils showed excessive surface leakage.

B_2 — Leakage so high that test voltage could not be applied. Considered to have failed. Coils were dried and tests continued but omitting moisture exposure.

B_3 — One coil intentionally tested to failure. Broke down at 11,000 volts.

B_4 — Remaining Class "B" coil tested on voltage to failure. Failed at 9,000 and 10,500 volts.

H — All Class "H" coils failed on application of 5,600 volts after heat aging.

CHART SHOWS the effect with an increasing temperature on Class A, B and H insulations during the heat aging cycles. **(FIGURE 3)**

test temperatures were raised to Class B temperatures. After failure, the Class A coils were quite brittle and the varnished cambric insulation had aged considerably. All of the Class A failures occurred on voltage application after the water immersion.

The type of construction used in the Class B mica coil appeared to be susceptible to water penetration after heat aging at test temperatures. At 180 C it became increasingly difficult to maintain the applied test voltage after water immersion. After the Class B coils were dried out they were satisfactorily carried along to the end of the test by eliminating further exposure to water immersion. Although the large flake mica insulation performed well when test samples were not immersed in water prior to application of test voltage, it must be said that it failed this particular type of aging test at the temperature involved.

According to the AIEE Test Procedure, the Class H test temperature and time for each aging cycle are 230 C for 96 hours with a probable life of 10 cycles. As shown in Figure 3, the Class H coil successfully withstood this test without failure, plus the aging of 15 cycles at 160 C and 180 C in addition to 4 cycles at 250 C and 280 C. The coil finally failed under the application of 5600 volts at temperatures of 280 C. The coils were found to have reduced elasticity, and had cracked through to the conductor around the end turns of the coil. The physical deterioration was not noticed, however, until removal of the half-lapped treated glass armor tape.

Motors insulated with properly processed and applied silicone rubber can be expected to give excellent service in severe moisture and high temperature applications. Initial dielectric strength of silicone-rubber insulation is ably retained for many cycles of exposure to accelerated service conditions, including heat, mechanical vibration, physical stress, voltage, and moisture. These tests demonstrate the superior heat and moisture resistance of silicone-rubber motor insulation when compared under similar test conditions to conventional Class A and B insulation.

Class A — multiple layers of half-lapped black varnish-cambric tape covered with one layer of half-lapped treated fiber-glass tape. The outer layer consisted of a high quality build-up of high-glaze varnish. The approximate ground wall thickness was 80 mils.

Class B — multiple layers of half-lapped paper-backed big flaked mica tape, covered with one layer of half-lapped treated fiber-glass tape on coil ends on one layer of butt joint asbestos tape on the slot portion and finished with a thin build-up of surface varnish. Approximate ground wall thickness was 90 mils.

Class H — multiple layers of half-lapped unsupported silicone-rubber tape with one layer of half-lapped glass-backed silicone-rubber tape for a top covering or armor. The approximate ground wall thickness was 80 mils. The slot portion and end portion of the coils, as well as leads and connections, were insulated with silicone rubber and paste. Organic materials were not used. The completed coils were vulcanized at about 149 C under controlled temperature and pressure.

CORONA TEST SOLVES DESIGN PROBLEM

by E. J. ADOLPHSON
Regulator Department
and
F. J. VOGEL
Pittsburgh Works
Allis-Chalmers Mfg. Co.

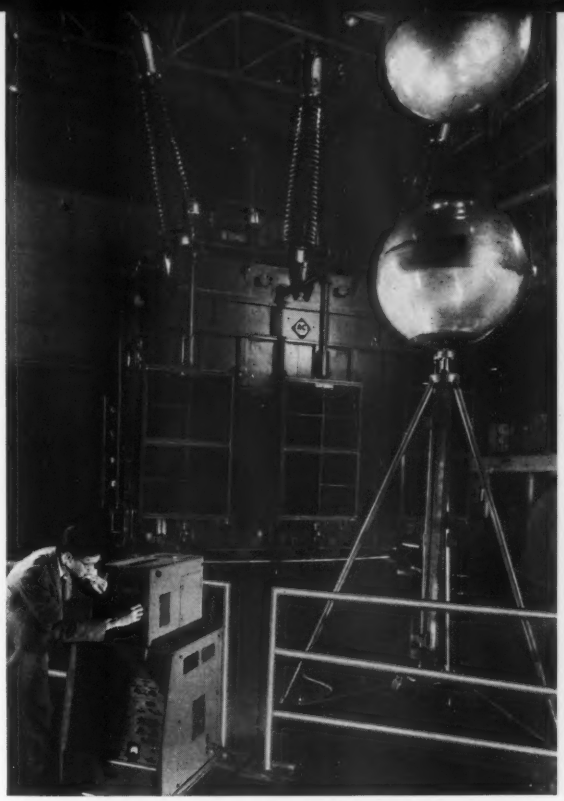
Extremely sensitive technique measures corona — enables transformer designers to make maximum use of insulation.

ONLY BY ELIMINATING the corona problem can the size of high voltage equipment be reduced.

Corona, which is an ionization of the dielectric material surrounding a conductor, occurs when the insulation material is overstressed by a high voltage. A corona disturbance is a sudden local breakdown of insulation resulting from ionization during an extremely short time interval. Over long periods of time even low values of corona can cause insulation deterioration and ultimate failure.

With reduced insulation transformers becoming more common, local corona at operating voltage is more likely to occur even when all the standard ASA tests are made.

In the past oil-insulated transformers have depended largely on oil itself for their insulation. Originally, transformers were not carefully vacuum treated and consequently corona occurred when they were tested at low frequency test values. Since the voltage stress under operating conditions was low enough to avoid the formation of corona, the transformers operated for years; however, it was found that such transformers did not have good impulse strength characteristics and designs were changed to eliminate corona at the test voltage, either impulse or low frequency.



TESTING CORONA on this 330-kv autotransformer is part of the normal procedure. Accurate corona measurements have helped reduce the BIL level in modern power transformers. Test voltage was 460 kv.

Capacitors also subject to corona problems

Since capacitors are often made of paper, foil and arochlor, chemical impurities in them may lead to a local weakness and result in the formation of corona. The arochlor will break down into carbon and hydrogen chloride which may destroy the paper and short the capacitor.

Corona may be formed in oil-impregnated paper cables either because of imperfect impregnation or as a result of excessive voltage stress that causes failure in voids between layers of paper[1]. This failure may be delayed and take place only when the cable is hot and carrying considerable current.

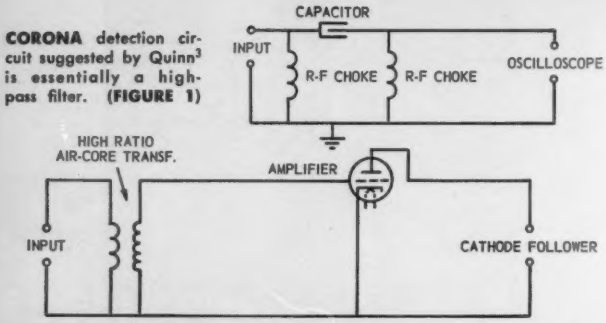
Testing methods show progress

Various methods have been used to determine the presence of corona. An early method used large numbers of insulation samples tested at different voltage levels. The corona point or maximum endurance point was found by failure of the samples and limiting design values were determined. Actual failure was sometimes accompanied by increased loss and increased capacitance of the samples.

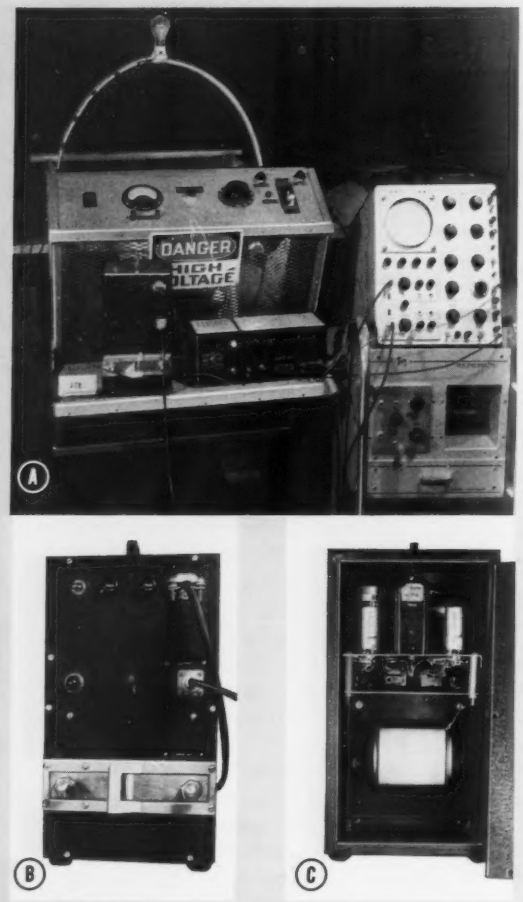
Another means of detecting corona is by measuring the microvolt level of radio interference voltage. This test also gives a true indication of corona, but the method is relatively insensitive and depends upon several variables, such as ambient disturbances, circuit constants and erratic occurrence of the corona pulses, over which there is no possible control. The microvolt readings might vary considerably for the same disturbance.

A balanced bridge circuit has also been used to detect corona. The high frequency transients which occur across the balance detection circuit are noted. These effects are

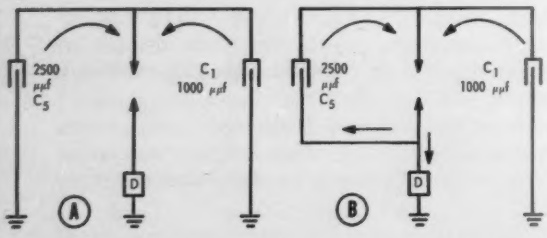
CORONA detection circuit suggested by Quinn[3] is essentially a high-pass filter. **(FIGURE 1)**



CIRCUIT DIAGRAM of electronic corona detector suitable for use in grounded circuit of large electric power equipment is shown. **(FIG. 2)**



CORONA DETECTOR, calibrator, oscilloscope, voltage source and sample are complete test apparatus for corona measurement (A). Gap on panel protects corona test equipment (B). Air-core transformer in bottom of case improves previous corona detection circuits (C). **(FIG. 3)**



TEST CIRCUITS show the effect of capacitance circuit constants on corona measurements. Circulating current in B subtracts from charge present at the detector with identical voltage sources. **(FIGURE 4)**

true indications of corona, but do not provide a good analysis of the quantity of corona formed.

The bridge circuit detector led to the use of electronic circuits for corona detection. These circuits measure the charge in micromicrocoulombs of a single corona pulse and are much more sensitive than any of the previously used methods[2].

The usual electronic detection circuit is a high pass filter composed of a radio-frequency choke or chokes and a small capacitor, shown in Figure 1. This circuit has been used for corona detection for years and was specified for testing radar transformers during World War II. It was rather difficult to make the radar transformer tests because of ambient electrical disturbance.

The usual small-size radio-frequency choke is unsuited for testing power transformers. An air-core transformer with a few turns of heavy wire in the primary and many turns in the secondary will measure directly the charge of a pulse passing through it. Figure 2 shows the electronic corona detector with the air-core transformers[2]. The complete test apparatus is shown in Figure 3.

Measurements are analyzed

Since the electronic corona test apparatus of Figure 2 measures the charge going through it, it is necessary to determine how this effect is related to the magnitude of the disturbance. Instrument sensitivity can be determined by applying a known charge to the sample under test, but there is no guarantee that the measured corona is the actual local disturbance in a part of the equipment[3, 4].

For example, a needle pointed toward a plain surface approximately 6 inches away showed corona at approximately 8 kv with a magnitude of 89 micromicrocoulombs. A capacitor of about 2500 micromicrofarads was then placed in parallel with both the needle gap and the detector. It might be expected that the corona voltage and discharge would be about the same with and without the parallel capacitor. In all the cases, the disturbance started at approximately 8 kv. With capacitor in parallel with both the gap and detector as shown in Figure 4*a*, the measured disturbance was 106 micromicrocoulombs. With the capacitor as shown in Figure 4*b*, it was reduced to 53 micromicrocoulombs. Actually, the pulse is so rapid that little or no charge is added but the charge is redistributed. Part of the charge involved in the redistribution is measured. The redistribution of charge is shown by the following analysis.

In Figure 5 the voltage V exists between A and ground and a charge exists between A and ground. C_2, C_3 and C_5 are the initial sample values and C_1 is the capacity of the source. C_4 is not initially in the circuit.

The corona effect is equivalent to increasing the capacity in the sample under test, or the sudden addition of C_4 to the circuit tends to reduce the voltage across C_2. However, if there is no change in the quantity of charge, the redistribution of voltage across C_2 will result in a redistribution of the charge, and change the voltage across C_1. The detector D will measure the quantity of charge involved in the redistribution from the initial C_1 value. The

arrows show the possible current directions during the redistribution.

Before adding the capacity C_4, the charges can be expressed as

$$Q_1 = V_1 \frac{C_2 \times C_3}{C_2 + C_3} + V_1 C_1 + V_1 C_5$$

After the addition of C_4, the charge would be

$$Q_2 = V_2 \frac{(C_2 + C_4)\, C_3}{C_2 + C_3 + C_4} + V_2 C_1 + V_1 C_5$$

The effect takes place instantaneously and no charge is added, since $Q_1 = Q_2$.

Then

$$V_1 \left[(C_2 \times C_3) + (C_1 + C_5)\,(C_2 + C_3) \right] = V_2 \left[\frac{(C_2 + C_3)}{(C_2 + C_3 + C_4)} \right] \left[(C_2 + C_4)\, C_3 + (C_1 + C_5)\,(C_2 + C_3 + C_4) \right]$$

$$\text{or } V_2 = V_1 \left[\frac{(C_2 + C_3 + C_4)}{(C_2 + C_3)} \right] \left[\frac{(C_2 \times C_3) + (C_1 + C_5)\,(C_2 + C_3)}{(C_2 + C_4)\, C_3 + (C_1 + C_5)\,(C_2 + C_3 + C_4)} \right]$$

The apparent charge measured by the detector will be

$$Q_D = V_1 C_1 - V_2 C_1$$

$$Q_D = V_1 C_1 \left[1 - \frac{(C_2 + C_3 + C_4)}{(C_2 + C_3)} \right] \left[\frac{(C_2 \times C_3) + (C_1 + C_5)\,(C_2 + C_3)}{(C_2 + C_4)\, C_3 + (C_1 + C_5)\,(C_2 + C_3 + C_4)} \right] \quad \text{Eq. 1}$$

Without C_3, Q_1 would be

$$Q_1 = V_1 C_2 + V_1 C_1 + V_1 C_5$$

or

$$Q_2 = V_2 (C_2 + C_4) + V_2 C_1 + V_2 C_5 \text{ and}$$

$$Q_D = V_1 C_1 \left(1 - \frac{C_1 + C_2 + C_5}{C_1 + C_2 + C_4 + C_5} \right) \quad \text{Eq. 2}$$

The above analysis shows that the measurement does depend on the circuit constants and this is demonstrated by the following analysis of the previous tests.

Case I — With the point gap and detector in Figure 4*A* both in parallel with the 2500 micromicrofarad capacitor:

$$Q_D \approx V_1 C_1 \left(1 - \frac{C_1 + C_2 + C_5}{C_1 + C_2 + C_4 + C_5} \right) \quad \text{Eq. 2} \quad (C_2 \text{ is small})$$

$$Q_D \approx V_1\, 3500 \left(1 - \frac{3500}{3500 + C_4} \right)$$

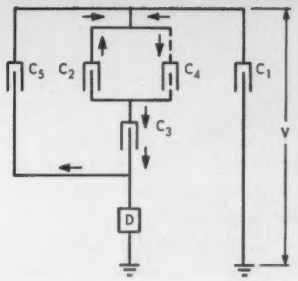
Case II — With only the point gap in Figure 4*B* in parallel with the 2500 micromicrofarad capacitor:

$$Q_D \approx V_1\, 1000 \left(1 - \frac{3500}{3500 + C_4} \right)$$

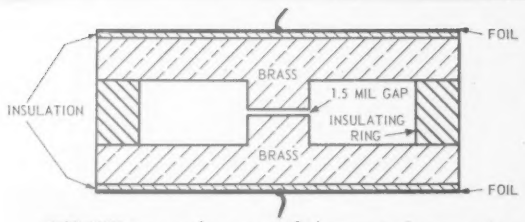
Even though actual values are not available, Case II confirms that a reduction in reading should be anticipated. The choice of constants is a reasonable approximation.

Corona is independent of inductance

Since the corona detector is proposed for testing transformers and windings, a set of tests with corona existing in different parts of windings will demonstrate its value.

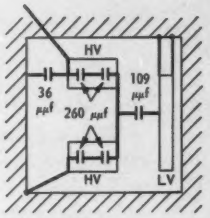


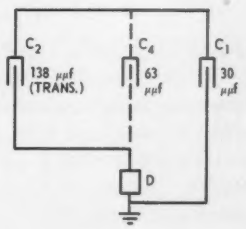
CORONA has effect of adding C_4 in equivalent capacitance circuit. Arrows show possible current directions during charge redistribution because C_4 is added. **(FIGURE 5)**



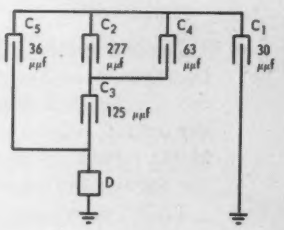
TEST GAP can produce a specified amount of corona at a predetermined voltage level. The equivalent capacitance is increased when the test gap breaks down. **(FIGURE 6)**

EQUIVALENT CAPACITANCE circuit of transformer that was tested is shown. **(FIGURE 7)**

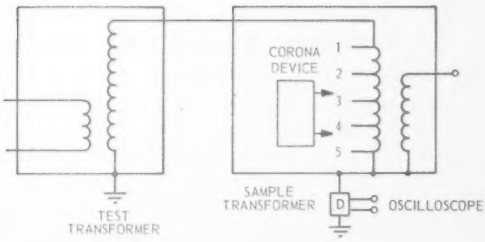




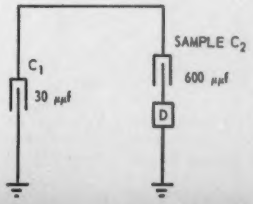
CIRCUIT shows the resultant equivalent capacitance with the corona device added across entire transformer. **(FIGURE 8)**



CIRCUIT shows resultant equivalent capacitance with the corona device added across the first quarter of HV winding. **(FIG. 9)**



TEST RESULTS in Table I were produced by attaching the corona device to several taps. **(FIGURE 10)**



TESTS on small barriers demonstrate the sensitivity of corona measurements. **(FIG. 11)**

A transformer was made with primary taps available at the mid-point and at either the ¼ or ¾ point. A device with metal electrodes about 1½ mils apart, shown in Figure 6, breaks down at about 700 volts and produces artificial corona. The discharge of the device was nearly the same no matter where it was in the circuit, and reliable estimates could be made of the charges involved. The capacitance through the device was found to be 17 micromicrofarads; with the gap shorted, the capacitance was 80 micromicrofarads. Therefore the flashover of the gap has the effect of a sudden addition of 63 micromicrofarads to the circuit.

The transformer equivalent capacitance diagram is shown in Figure 7. The equivalent capacitance of the supply transformer to furnish the test voltage was not measured, but can be estimated to be 30 micromicrofarads. With the corona-making device across the whole transformer and by combining capacitances, the equivalent capacitance network appears as in Figure 8. According to Eq. 2:

$$Q_D = 700 \times \sqrt{2} \times 30\left(1 - \frac{30+138}{30+138+63}\right)$$

$$Q_D = 8100$$

With the corona device across the ¼ tap the equivalent capacitance network is shown in Figure 9. According to Eq. 1:

$$Q_D = 700 \times 4 \times \sqrt{2} \times 30 \left[1 - \frac{465}{402}\left(\frac{277 \times 125 + 66 \times 402}{340 \times 125 + 66 \times 465}\right)\right]$$

$$Q_D = 4000$$

The test results in Table I do not check as closely with Equations 1 and 2 as can be expected, but they do indicate that the theory of this method of corona testing is generally correct. Figure 10 shows the test circuit arrangement of the sample transformer. The corona voltage induced was measured by an oscilloscope.

Table I shows that the transformer inductances are not concerned in corona tests. Only the circuit equivalent capacitance is affected because of the extremely short duration of the test phenomena. The test voltages were of the same relative order of magnitude independent of the location of the corona disturbance. Measuring the charge directly makes use of uncomplicated equipment and produces more accurate results than earlier detection schemes.

Small additions are accurately measured

The corona voltage measured by the detector is an apparent value, not necessarily the true value. For example, the corona manufacturing device transfers a charge of $700\sqrt{2} \times 63$ micromicrocoulombs, or 62,000 micromicrocoulombs. To this charge is added the internal capacitance of the corona device which discharges about 21,400 micromicrocoulombs. Because of the parallel paths, only part of this charge appears in the detector circuit.

Even though the apparent detector charge might appear to be not too precise a measure of the corona disturbance, a consideration of tests on small barriers about 60 mils thick and 6 inches in diameter will demonstrate the great sensitivity of the test procedure.

In the circuit in Figure 11 corona was indicated at about 30 kv at a level of 15 or 20 micromicrocoulombs. The Q originally in the capacitance of the circuit would be $630 \times 30{,}000 \times \sqrt{2}$. If C_3 is a capacitance addition because of a corona disturbance, the new Q would be $(630 + C_3) \times V_2 \times \sqrt{2}$. Therefore: $V_2 = V_1\ (630/630 + C_3)$. The quantity of charge, Q_D, transferred through the detector would be

$$20 = V_1\, C_1 - V_2\, C_1 \text{ or}$$

$$20 = 30{,}000\ \sqrt{2} \times 630\left(1 - \frac{630}{630 + C_3}\right)$$

Solving for C_3:

$$C_3 = \frac{20}{30{,}000\ \sqrt{2} \times 630} \times (630 + C_3)$$

This is practically:

$$C_3 = \frac{20 \times 630}{42{,}500 \times 630} = 0.00047\ \mu\mu f$$

The transformer equivalent capacity could increase and the sample capacitance could vary over a relatively wide range without affecting the accuracy of results. In other words, an apparent capacity addition of 0.00047 micromicrofarads over 600 micromicrofarads, or 0.00008 percent, is detected. After a considerable length of time this small initial value of corona increased and failure resulted.

Low values of corona discharge can cause failure; therefore extremely sensitive devices must be used for detecting disturbances. Because of increasingly sensitive corona detection, transformers with improved impulse characteristics are made smaller, lighter and with better insulation properties.

TABLE I

CORONA TEST RESULTS

Corona Device Location	Corona Voltage (rms)	Voltage on Corona Device	Charge Through Detector ($\mu\mu$C)
1 to 5	755	755	8530
1 to 4	935	717	6940
1 to 3	1480	740	8000
1 to 2	2730	633	8000
2 to 5	1050	807	6400
3 to 5	1680	840	5780
4 to 5	2730	633	5600

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4 "A Method for Detecting the Ionization Point of Electrical Apparatus," G. E. Quinn, AIEE *Transactions*, page 680, Vol. 59, 1940.

HOW TO...
SIMPLIFY MOTOR POWER-FACTOR CORRECTION

by G. R. BROOKS
Motor-Generator Dept.
Allis-Chalmers Mfg. Co.

Simple chart provides quick answer to induction motor power-factor correction problems.

TWO IMPORTANT power-factor questions can be solved with a compass, straightedge and graph paper:

(1) How much capacitance is needed to correct the power factor of an induction motor?

(2) What power factor will be obtained with a given capacitor and motor?

Use of the chart requires only motor name plate and no-load current data. The no-load current may be measured or obtained from the motor manufacturer.

For the sake of simplicity, it is assumed that the amount of capacitance used will in no case exceed the no-load motor kva and that the motor does not overspeed when disconnected. If more capacitance is desired or if overspeed should occur, a closer study should be made.* It may be necessary to select a capacitor location other than on the motor side of the motor starter.

A large sheet of graph paper suitable for showing a quadrant of a circle having a radius of 10 units, each unit easily divisible by 10, is used. The quadrant is drawn as shown in Figure 1. Then a dot is placed on the quadrant at its intersection with each horizontal unit line. Radial lines are drawn from the center of the quadrant to each of these dots. The power-factor values are added to the chart as shown. The 1% divisions are indicated in like manner.

Capacitor size is in percent of rated motor kva as measured horizontally from full-load power-factor point on the quadrant to radial line of power factor as corrected.

Example shows chart application

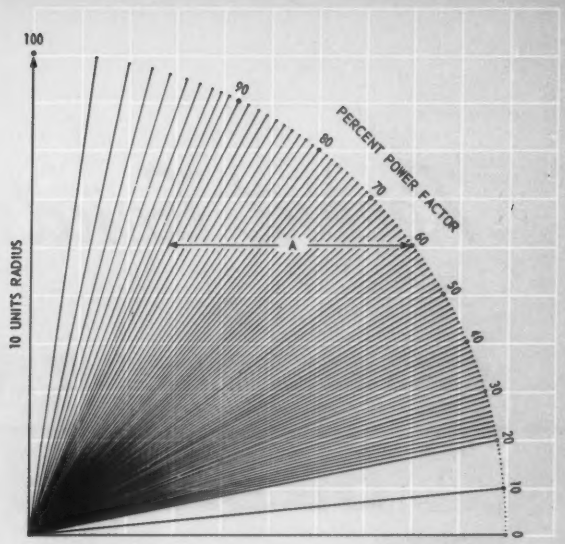
Given a 1000-hp, 2300-volt, 346-amp, 3-phase, 60-cycle, squirrel-cage induction motor with full-load PF of 60% and no-load current of 190 amps, how much external capacitance is required to raise power factor to 90%?

Let E = phase volts, I = phase amps, m = phases.

$$\text{No-load kva} = \frac{E \times I \times m}{1000} = \frac{2300}{\sqrt{3}} \times \frac{190 \times 3}{1000}$$

$$= 757 \text{ kva}$$

$$\text{Full-load kva} = \frac{2300}{\sqrt{3}} \times \frac{346 \times 3}{1000} = 1380 \text{ kva}$$



CAPACITOR SIZE obtained from the chart, as shown by line *A*, is in percent of rated motor kva and is measured from power-factor point to radial line of higher power factor desired. **(FIGURE 1)**

From the chart in Figure 2, 51% of full-load kva or $.51 \times 1380 = 704$ kva of capacitance is required to correct from 60% to 90% power factor.

The 704-kva capacitance does not exceed the 757 kva at no load and can therefore be located across the motor terminals with safety if the motor coasts rather than overspeeds when removed from the line.

What power factor will be obtained if a 500-kva capacitor is used instead of the 704-kva rating?

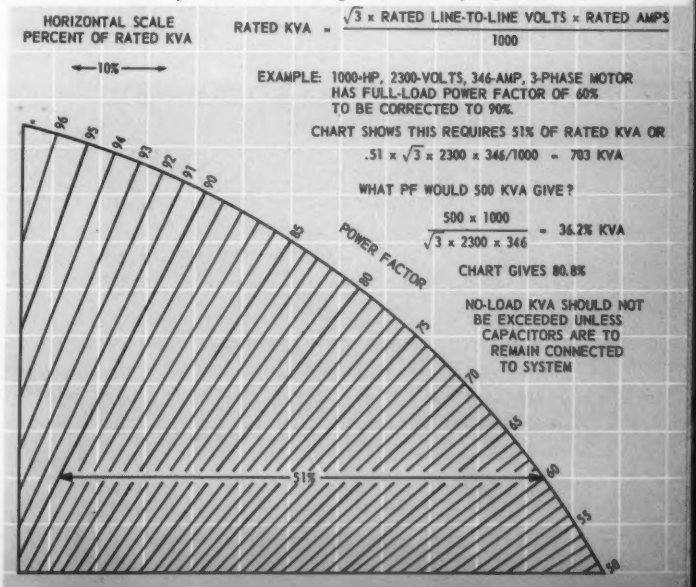
$$\text{Percent of rated kva} = 500/1380 \times 100 = 36.2\%$$

When 36.2% is laid off horizontally from the 60% PF full-load point, 80.8% power factor is obtained.

The chart provides quick answers to the two common problems on motor power factor — the quantity of capacitance needed to correct a given power factor, and the power factor obtained when using a given capacitor. Once constructed, the chart will apply for any induction motor.

* "Applying Capacitors at Motor Terminals," R. C. Moore and W. E. Schwartzburg, *Allis-Chalmers Electrical Review*, 4th Quarter, 1958.

ENLARGED portion of chart may be used for most power-factor correction problems to obtain greater accuracy. **(FIGURE 2)**



Recent Trends IN CONDENSER DESIGN

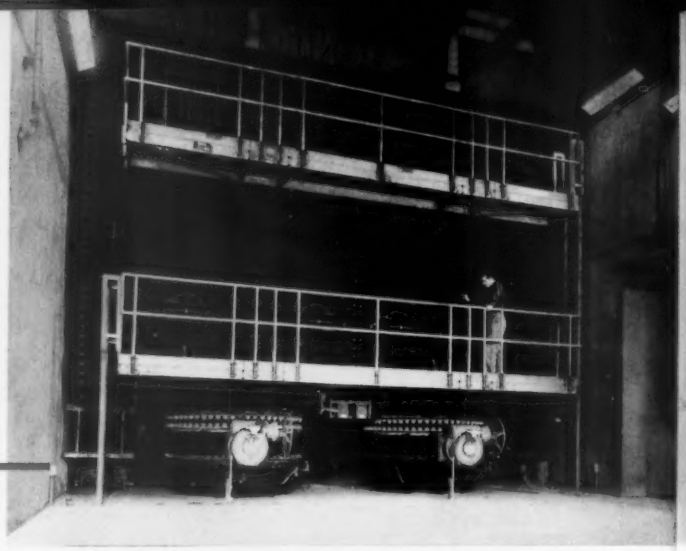
by J. S. FERGUSON
Heat Transfer Dept.
Allis-Chalmers Mfg. Co.

Today's condensers are called upon to do more in less space. Steam generator advances are affecting condenser designs.

SPACE IS AN IMPORTANT PROBLEM when locating large condensing units. The physical limitations being placed on equipment naturally present problems that are a real challenge to the condenser designer.

Space limitations have dictated a trend toward the use of rectangular condensers employing fabricated steel water boxes. The use of steel allows greater freedom in location of water nozzles and other special connections without the necessity of expensive pattern changes. Also, for comparable duty, a steel water box will be lighter than one of cast iron.

Development of internal water box coatings has promoted the use of fabricated steel in locations where circulating water may be corrosive. Rubber coatings have been used successfully under such conditions, and the newly developed epoxy coatings appear to be proving equally effective.



WORLD'S LARGEST CONDENSER has 200,000 sq ft of condensing surface. The rectangular construction makes complete use of available space. The water box, made from fabricated steel, is 17 by 26 feet.

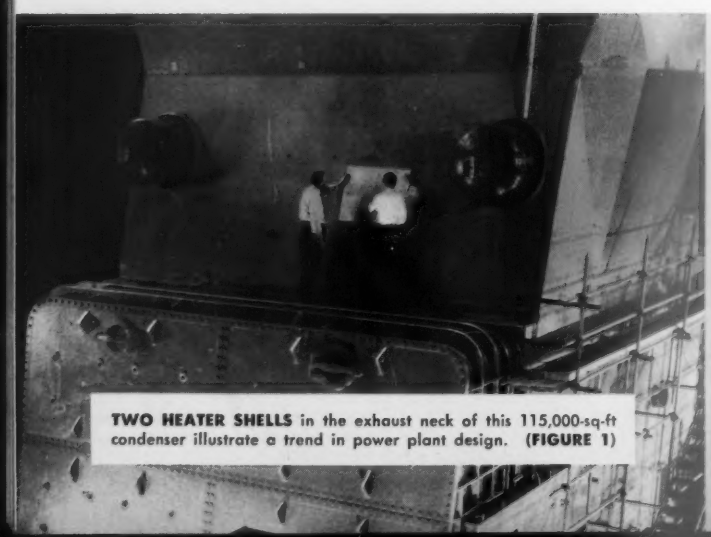
Vertical pumps have advantage

Vertical condenser circulating pumps are being used to save horizontal space and basement height. The column type is most prevalent. Vertical mixed-flow volute and double-suction centrifugal pumps are, however, also used. These pumps are mounted in a vertical position and have a long shaft extension for mounting the drive motors above flood-stage water level. Vertical pit condensate pumps are commonly used to reduce the basement excavation otherwise necessary for horizontal pumps.

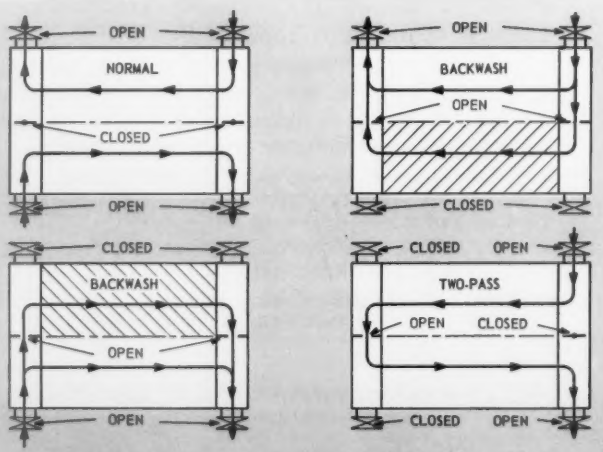
For some years plant designers have been using the space in the condenser neck to install heaters with extraction piping, and more recently steam dump systems. With installation of more equipment in the exhaust neck, excessive pressure drop between the turbine and condenser must be avoided. Figure 1 illustrates a unit with two heater shells in the exhaust neck.

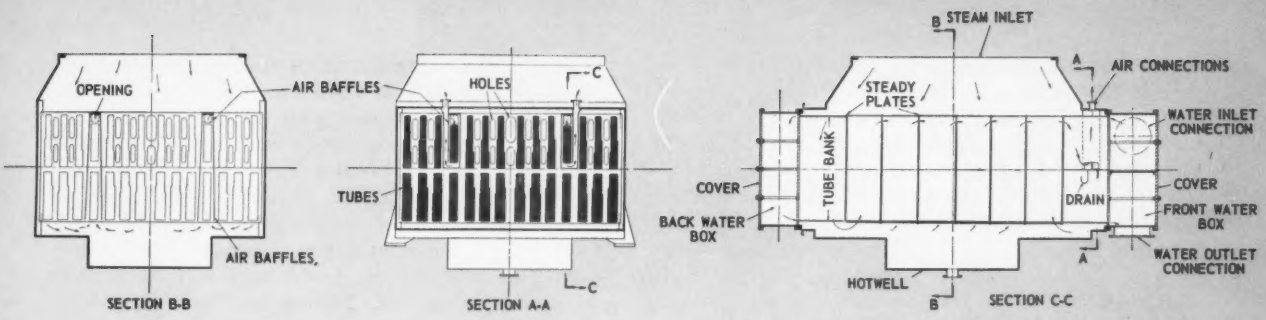
As system loads increase and more and larger generating units are installed, water limitations are becoming critical in some areas. The availability of water may limit future plant sizes; however, cooling towers will help to relieve this situation.

In a great many locations river flows vary considerably from summer to winter. Generally, in these areas after consideration of pumping costs, physical size, and other similar factors, single-pass condensers are used with large



TWO HEATER SHELLS in the exhaust neck of this 115,000-sq-ft condenser illustrate a trend in power plant design. **(FIGURE 1)**





GUIDED FLOW condenser design has been devised for service with the modern generating unit. **(FIGURE 3)**

generating units. However, a single-pass condenser will require approximately 40 to 50 percent more circulating water than a two-pass unit serving the same size turbine. Where a limited amount of circulating water is available, total plant generating capacity would therefore be greater using the two-pass condensers.

The circulating water arrangement in Figure 2 was originally devised in the late 1940's for backwashing. However, the system has been adapted for use in the above situation where water quantity is limited during part of the year. In the winter, when river flow is high, the condenser is operated as a single-pass unit. When river flow decreases, the needed capacity can be gained by operating the unit as a two-pass system, permitting full-load operation with no loss in vacuum.

Larger units take special facilities

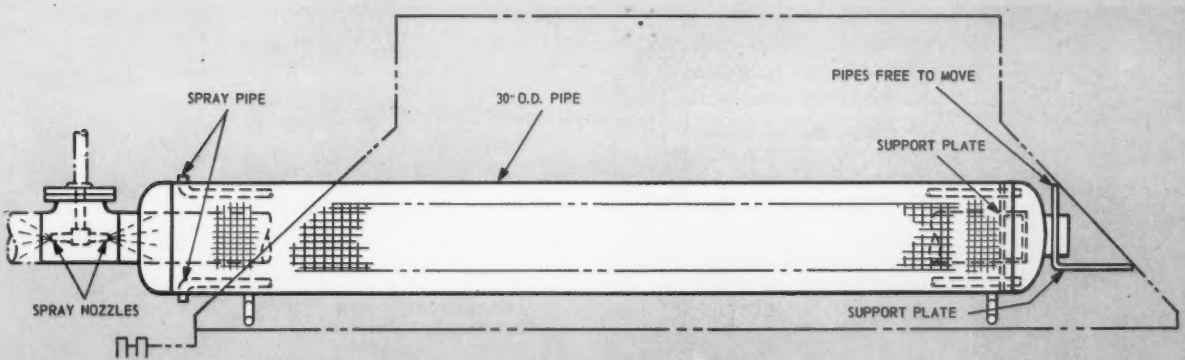
As condensers become larger, either their parts become larger or the equipment must be fabricated in more pieces, thus complicating field assembly. Use of modern manufacturing facilities makes possible the fabrication of pieces limited only in size by shipping clearance. Special well-center railroad cars have been built to take maximum advantage of presently available rail clearances. In some instances units have been shipped by Great Lakes freighter, allowing fabrication of even larger pieces.

Increased boiler pressure and temperatures have made deaeration and feedwater treatment more exacting. Many plants are operating with boiler feedwater on the basic side to reduce its corrosiveness. The pH of the feedwater is generally controlled by use of amines which may eventually break down into ammonia that can seriously attack copper alloy tubes. Proper design of the air-cooling section will limit the harmful effect of the ammonia on copper tubes.

The air-cooling section shown in Figure 3 minimizes the effect of the concentration of ammonia. A minimum number of tubes are exposed to concentrated noncondensables. With this arrangement, as added assurance, tube material such as duplex or stainless steel may be used in the air-cooling section without adding greatly to cost. The air is removed at the coldest end of the condenser, and the inlet to the air-cooling section is immediately above the hotwell for most effective deaeration.

Steam dump systems require consideration

Many modern condensers are equipped with a steam dump system. Units of this type generally serve once-through or nuclear steam generator installations, although some are used in connection with conventional plants to dump steam from the reheat boiler in case of turbine trip-out. The once-through steam generator requires water circulation while starting or shutting down the unit. During this time, the generated steam is bypassed directly to the condenser until steam conditions are suitable for turbine operation. This once-through design, as well as most nuclear steam generators, generally include a dump system for start-up, shutdown, and turbine trip-out and in some instances for control of the steam cycle.



SINGLE-PASS, opposed flow, water side condenser design has allowed several utilities to use single-pass operation in the winter. During the summer two-pass operation is usual, because plant size is limited by the available water flow at the plant. **(FIGURE 2)**

STEAM DUMP arrangement is designed for planned service on start-up, shutdown and for emergency service on trip-out. Condensate is sprayed into inlet pipe to reduce temperature, and the resulting expansion through perforated pipes reduces the pressure. **(FIGURE 4)**

The steam dump system may consist of a water spray immediately adjacent to the condenser to knock out temperature, and a series of perforated pipes within the condenser to knock out pressure. The system can be installed immediately above the hotwell to reduce heating of the turbine exhaust end. However, because of the lack of space below the tube bank, special arrangements, shown in Figure 4, have been installed in the condenser neck.

With conventional steam generators, allowable boiler contamination has generally been referred to in parts per million. With the once-through design it is spoken of in parts per billion. Under this arrangement, because water enters the boiler tube as a liquid and emerges from the same tube as superheated steam, solids in the water could drop out on the boiler tubes, resulting in possible tube failure. Feedwater purity requirements have resulted in a reappraisal of all possible locations in a power plant cycle where contamination could occur. Possible source for such contamination is the tube to tube sheet joint. A carefully prepared rolled joint is sound; however, for added assurance other arrangements have been considered.

Double tube sheets, shown in Figure 5, with the tubes rolled into each sheet, have been used in several nuclear plants, both land and marine.

Over 300,000 sq ft of condensing surface have been welded, with several condensers, such as the 90,000-sq-ft unit in Figure 6, presently operating satisfactorily.

At one time mechanical air removal equipment was generally preferred. However, in recent years the steam-jet air ejector has been adopted almost exclusively. But today the trend is returning to the mechanical type. This reversal is partly due to a lack of suitable steam for ejector operation during plant start-up. To meet this condition, a two-stage rotary vacuum pump, shown in Figure 7, has been developed for condenser service.

New tube materials being used

Copper alloys have long been considered standard material for condenser tubing. Recent development has made other materials acceptable for this duty. Among the suitable materials is aluminum. Aluminum tubes have been installed successfully at a considerable saving in several condensers where circulating water conditions were favorable.

The decision to use aluminum tubes is one that should rest on individual plant conditions. Copper must not be used in a system equipped with aluminum tubes, since copper will promote destruction of such tubes from the water side. Selection of alloy is of course important because of the circulating water conditions, and also because aluminum is softer than copper alloy. In an aluminum tubed condenser erosion of top tubes can be serious.

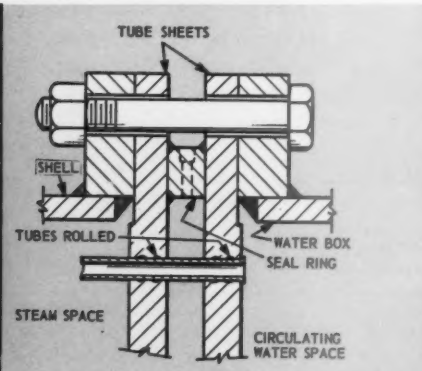
Another tube material found suitable for condenser service is stainless steel. Stainless steel has a lower heat-transfer rate than copper, which would normally result in a larger condenser, and is considerably more expensive than copper. However, the most important consideration may be resistance to corrosion. Circulating water in some highly industrialized and tidewater areas may be so corrosive as to prohibit the use of copper alloys. Because of superior corrosion resistance, 20 and 22 gage stainless tubes may be used where 16 or 18 gage copper tubes were used previously. Thinner tubes reduce cost and provide better heat-transfer.

Erosion of top tubes by wet steam exhausting from a turbine has long been a problem in areas where very cold circulating water is available. With some of today's large generating units, condenser necks are necessarily quite short, bringing the tubes closer to the turbine exhaust. Tube erosion and copper pickup can be a problem in such an installation. Duplex or stainless steel tubes may be used in the top rows because of their erosion resistance. Duplex tubes have copper on the water side and stainless on the steam side. This type of tube may be used because of water side cleaning requirements, since acid for cleaning copper alloys may be very harmful to stainless steel. Stainless steel tube protector clips may be used on existing installations, or where the added expense of stainless steel tubes is not desired. The clips fit over tubes of any diameter, preventing further erosion damage to the tube.

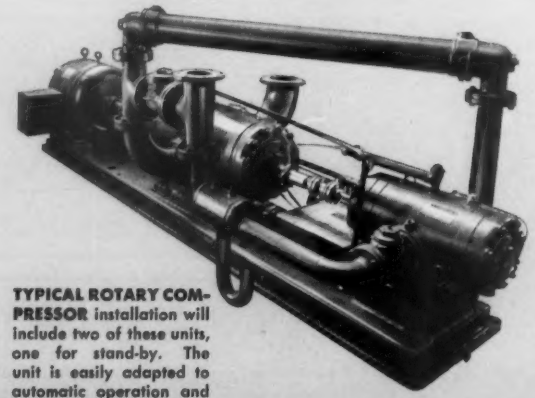
Future power plants may use carbon steel or wrought iron tubes to eliminate copper pickup rather than the more expensive stainless steel tubes, although iron pickup may present problems.

The advances in the electric power industry will uncover new problems that must be solved. Several conditions can be foreseen that will affect condenser design. Water is scarce in some areas and is becoming scarcer. Lack of water may well change the condensing cycle as we know it today. Absolute tightness and elimination of copper and iron pickup will become increasingly important, stimulating use of new materials and construction features.

FIRST CONDENSER ever to have the tubes welded to the tube sheet is this 90,000-sq-ft unit. The welding techniques and equipment were developed after considerable research. The unit has seen more than a year of successful service with the first subcritical pressure, once-through boiler installation in the United States. **(FIGURE 6)**



DOUBLE TUBE-SHEET arrangement insures against condensate contamination from the water side through the tube-to-tube sheet. The joint has found use in several nuclear power plants. **(FIGURE 5)**



TYPICAL ROTARY COMPRESSOR installation will include two of these units, one for stand-by. The unit is easily adapted to automatic operation and may be used for hogging service. **(FIGURE 7)**

TURNING LARGE KILNS

MASTER PANEL is example of trend toward centralized control of cement plant operations. Meters and instruments provide complete process data. Controls start and stop all the necessary equipment.

by W. G. LEFFERTS
Processing Machinery Dept.
Allis-Chalmers Mfg. Co.

Coordinated kiln drives provide maximum reliability for today's closely controlled thermal processes.

ROTARY KILNS, the largest of industrial rotating equipment, are vital not only to the cement industry, but to other process industries for heat-treating a variety of materials ranging from calcium carbonate to ilmenite and from lithium to iron ore. New uses for kilns include nodulizing metallic ores and certain extraction and reduction processes. As applications vary so do their drive characteristics.

Kilns are now being built as long as 610 ft and over 18 ft in diameter. Despite their immense size, they do not require extremely large motors because of their slow speed and their carefully balanced design. Owing to the nature of the load, normal machine or constant-torque load curves do not apply. While an adjustable-speed drive is usually required, the control need not be extremely precise.

Load characteristics are influenced by the variable loading of the material as it moves along the length of the kiln, and also by the heat-transfer chains and refractory brick kiln lining.

The required daily output of product, type of feed and fuel determine drive horsepower. The selection of either a single or dual drive is based on economics, overall reliability and ease of maintenance. The usual dividing line between single and dual drives is about 200 hp.

Portland cement is most important product

In the manufacture of portland cement the kiln performs three basic functions: dehydration, calcination, and burning, or causing the reaction of calcium oxide and silicon dioxide.

The raw kiln feed, a mixture of limestone and clay or shale with additives to promote the process, is dehydrated while in the relatively cool intake end of the kiln. In the wet process, where the raw mixture is fed into the kiln in the form of a slurry, a chain heat-transfer system is used to promote the drying of the slurry.

In the dry process the solid material, containing some moisture, is dehydrated while rolling around in the kiln. Since kilns are always mounted on a slope to the horizontal, the material gradually works its way through it as the kiln rotates.

While the material progresses through the kiln, its temperature increases and calcination becomes virtually complete by the time the material has reached a temperature of about 2000 F near the output end of the kiln. Due to the slow speed of rotation, about 1 rpm, the material becomes sufficiently hot to complete calcination.

The calcium silicates, which form the active ingredient of portland cement, are formed in the hottest end of the kiln. Here temperatures range from 2700 to 3000 F and are intense enough to render the surface of the nodules, or chunks of cement clinker, plastic. Subsequent quick cooling below white heat renders the clinker almost impervious to moisture. The clinker can then be stored in the open for some time before being ground into cement.

Horsepower is based on empirical data

In calculating the horsepower required to turn a kiln, two factors are considered — the friction of the support rollers, gearing, and kiln seals, and the power required for moving the material. The calculation is based on the maximum speed for which the kiln is designed. The friction horsepower may vary from 10 to 30 percent. The loaded area in a kiln may vary from 4 to 10 percent, depending upon the rate at which heat can be transferred to the material without damaging the brick lining of the kiln.

Although two kilns installed side by side are the same size and are fed with the same material, each will burn differently. Since 70 to 90 percent of the input torque is required to move the material, any change in material characteristics will greatly affect the torque required, even though the loaded area may remain constant in the kiln. The flexibility needed for this erratic-type load can be provided by a number of types of electrical drives. The most common are constant-potential dc drives, adjustable-voltage dc drives, eddy-current couplings, fluid couplings, variable-speed ac wound-rotor motor drives, and multi-speed cage motor drives.

The constant-potential dc system consists of adjustable-speed dc motors having shunt field weakening control with a 3 to 1 or more speed range. The motors are supported by one or more constant-potential generators, rectifiers or other source of dc. While a small number of these systems may be too costly, the system becomes competitive where more of these drives are used. Because the load is essentially constant torque, the motors are larger than necessary for slow speed operation. However, the use of this system assures smooth and easy starts without commutator sparking, regardless of ring formation in the kiln.

Each motor has its own control with automatic acceleration in steps, field loss protection, and a field economizing circuit to prevent detrimental high voltages from being generated when the kiln rolls back under its load after stopping.

Dc generators supply the power

Motor-generator sets are generally preferred for dc supply because of their reliability and ease of maintenance.

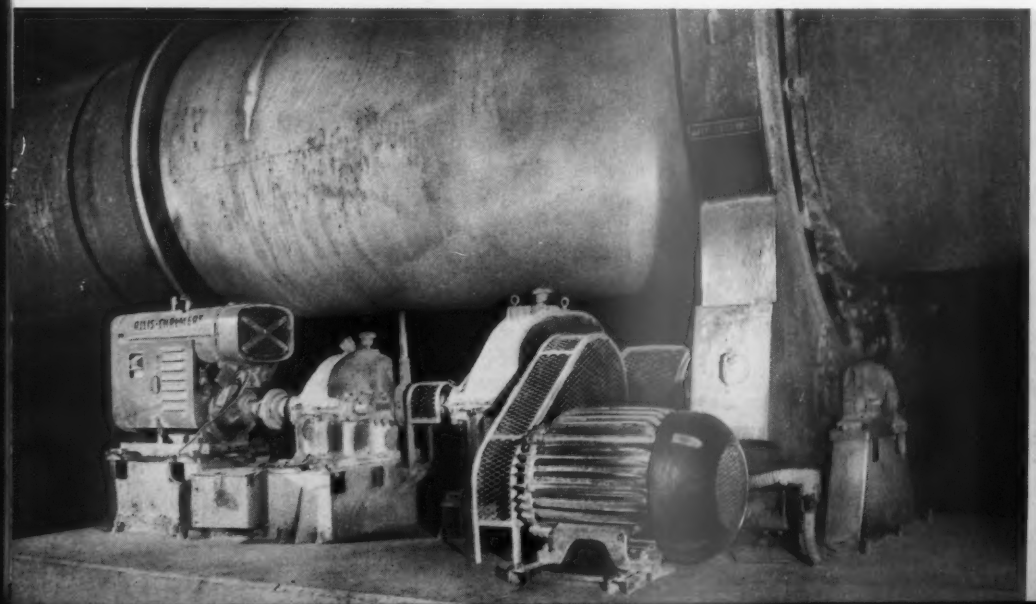
To attain the maximum continuity of supply required by a kiln, more than one m-g set should be paralleled to a dc bus and sized for minimum and maximum dc requirements. Where the kiln can require 70 percent of the dc capacity, certain precautions are necessary in the dc controls. The dc generators should be properly compounded to share the load under all demands; and they should either be flat-compounded or not more than 5 percent over-compounded.

When the kiln is rapidly accelerated or decelerated by adjustment of the field rheostat, heavy forward or reverse currents can be drawn or generated by the kiln drive motor or motors because of the inertia of the kiln. To prevent heavy surges of reverse or forward current, current-limiting relays are incorporated in the kiln drive motor controls. Two conditions exist under which these current surges can be tolerated: (1) when all dc is fed from a single m-g set; (2) when the kiln requires less than about 70 percent of the dc demand.

If the generator sets are operated in parallel, the following devices are needed: reverse current, instantaneous and thermal trips for three poles to the dc supply and equalizer buses; reverse current trips, to prevent motoring of the generator and consequent depolarization of the generator in case of ac power failure; instantaneous trips, to prevent commutator damage; thermal trips, to prevent insulation or commutator damage resulting from high temperatures. Usually relays are used to operate breaker shunt trips which open the dc breaker in case of ac power failure or momentary low ac voltage.

Adjustable voltage dc

Adjustable-voltage dc drives must be chosen carefully, since peak starting and running torques will exceed normal running torques. It may be necessary to oversize the motors and generators or select a motor with much lower base speed than the maximum operating speed. In the latter case the motor should have maximum field strength when operating at the lower speed range. The excitation requirements must be fed from a constant-voltage source, such as a compound-wound exciter or an electronically regulated rectifier. The adjustable-voltage source may be either a rotating generator or a magnetic amplifier con-



LIME KILN drives include both an induction motor and gasoline engine. Operation with motor is usual. Clutch handle engages engine if power should fail, to prevent warpage of the kiln.

ADJUSTABLE DUAL-SPEED drive with 75-hp motors and auxiliary gasoline engine drives an 11 by 375-ft rotary kiln. Kiln speed tachometer generator and synchronous tie alternator are shown at lower right.

trolling saturable reactors. However, for the sizes usually encountered in kiln drives, it is usual to use a rotating generator with magnetic-amplifier-controlled adjustable excitation. This feature facilitates speed control from a remote location by means of a small rheostat. Likewise, it renders automatic control of speed less difficult than with a constant-potential field weakening motor. Such drives require means for limiting the rates of acceleration or deceleration to prevent damage to commutators from current surges.

Despite these factors, however, the adjustable-voltage system has many advantages for kiln drives. When the speeds of two or more motors, such as kiln and feeder drives, are to be closely synchronized, motors can be connected in parallel across the adjustable-voltage generator. Kiln dual-drive motors also tend to deliver the same torque output when the motor armatures are connected in series across the adjustable-voltage generator; however, the voltages across the armatures should be equal for proper operation of the combination. A disadvantage of this system is the source of adjustable voltage.

When several motors are furnished power from a multiple generator source, the possibility of failure is less than with an adjustable-voltage drive having one motor supplied from a single source. A properly designed constant-voltage system should, therefore, be more reliable than a group of adjustable-voltage systems. Usually maintenance personnel prefer the more familiar motors, generators and contactors than magnetic amplifiers and rectifiers which tend to reduce maintenance expense.

Eddy-current couplings

Eddy-current couplings are variable-speed devices with their speed output electronically stabilized.

When considering only kiln drives or, at most, kilns and feeders, the eddy-current coupling is quite versatile and economical in first cost. However, it is rather inefficient electrically at speeds below 80 percent. In addition to this, special precautions must be taken in the design of the driven member to prevent damage on kiln roll-back resulting from overspeed. Dynamic braking can be accomplished by braking and holding the cage rotor of the motor before roll-back occurs, or by using coupling-brake combinations.

Eddy-current couplings can be readily used in pairs for dual drives in sizes suitable for kilns and may be water cooled or air cooled. Overhung loads tend to present problems in belted drives, and direct-coupling to gear reducers tends to lessen flexibility in comparison to motor drives using V-belts and reducers. Maintenance of electronic power supply for these drives may require specialized personnel. Both couplings and motors must be adequately sized to supply the maximum peak torque required by the kiln.

Coupling manufacturers have tended to overlook the requirement for abnormally large torques at low speeds for comparatively long periods. Recent operating reports indicate that air-cooled couplings with magnetic-amplifier control are remarkably reliable and maintenance-free in sizes up to about 150 hp. Speed stability seems excellent.

Fluid couplings

Fluid coupling maintenance and control generally compare to that of eddy-current couplings. However, remote control is not as practicable with fluid couplings.

Constant speed of the kiln cannot be held to prevent minor instantaneous changes in speed with small changes in load. Electronic proportioning controls with reset will be necessary to hold an average constant speed obtained with eddy-current couplings. Instant starting and stopping of this type of drive cannot be achieved because fluid cannot be pumped into or emptied from the impellers instantaneously. Some time lag will always exist in the control of this coupling.

Variable-speed ac drives: wound-rotor motors

The oldest and probably most frequently used kiln drive is the wound-rotor motor drive. On large kilns, this type of drive is not practical because of the expense involved in installation and because of its poor efficiency. The efficiency of wound-rotor motors, fluid couplings and eddy-current couplings is approximately the same at reduced speeds.

Adequate controls for wound-rotor motor drives are expensive, and since normal operating speeds will range from 80 to 90 percent of maximum much wasted power will result. On these large drives, speed regulation is remote from a pushbutton station because secondary resistance should be physically located near the motors. Otherwise, large secondary cables must be run from the motors to the drum controllers at the burner panel. These motors will seldom start on the first speed-regulating resistor steps but on the succeeding lower resistance step. After starting, the rotor resistance is increased to provide the lowest speed ranges. Speed regulation is very poor at low speeds; therefore ranges greater than 2 to 1 should not be used.

Four-speed squirrel-cage motors

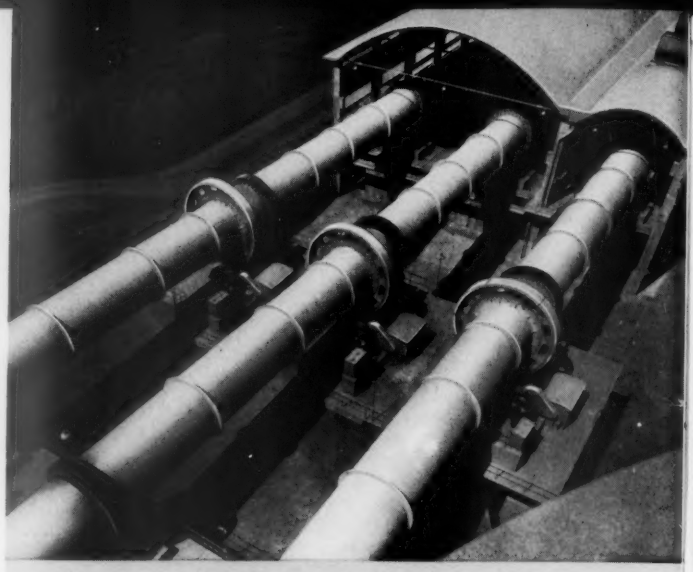
Although very popular for calcining kilns, the two-winding, consequent pole, constant torque, four-speed cage motor is not very suitable for cement kilns. Since normal operation should coincide with next to the highest speed and the speeds are so different, proper cement burning becomes difficult. These drives are limited to about 150 hp, because above this rating these motors will not divide their loads properly operating as dual drives. To prevent damage to the bearing surfaces of the kiln support rollers, it is recommended that compelling relays be provided on the controls for the larger kilns to enforce starting at the lowest speed.

Enclosure requirements are usually simple

Nearly all cement kiln drive motors are of dripproof, dripproof fully protected, or splashproof construction with antifriction bearings for mounting on a slope of about ½ inch per foot. More elaborate enclosures are usually unnecessary because there is ordinarily not much dust at the kiln drive. In unprotected installations where dusty atmospheres or driving rains can cause trouble, more elaborate enclosures, such as total enclosures for forced-air cooling or some form of heat-exchanging machinery built directly on the motor, would be required.

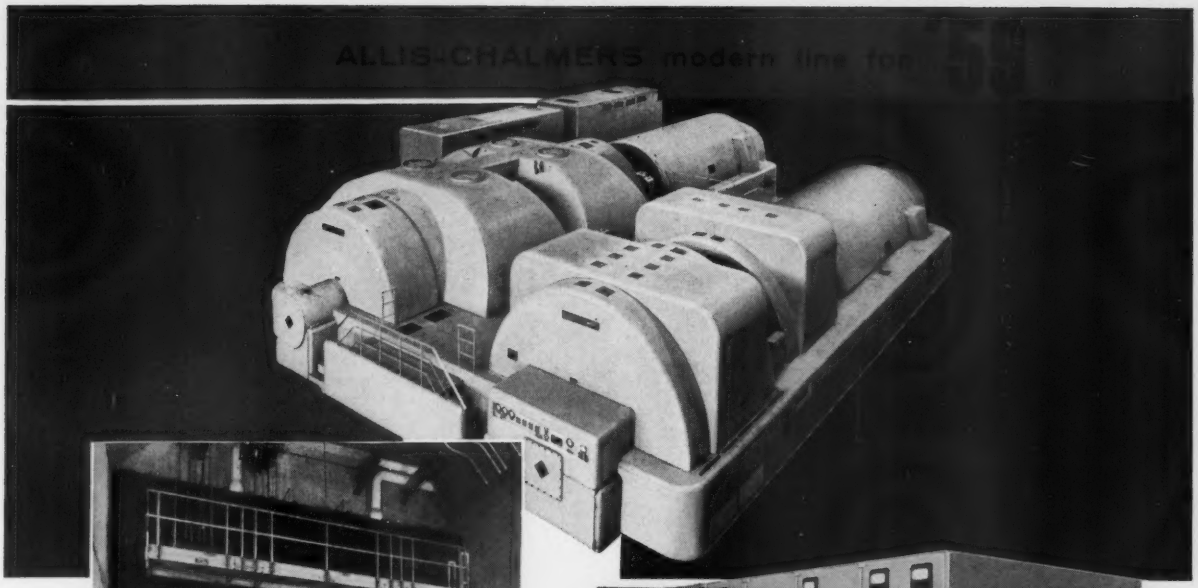
Kiln drive motors are usually subjected to high ambient temperatures, particularly during warm weather. Heat-reflecting shields between the kiln and its drive motor will be effective in reducing the motor temperature and can provide protection from rain.

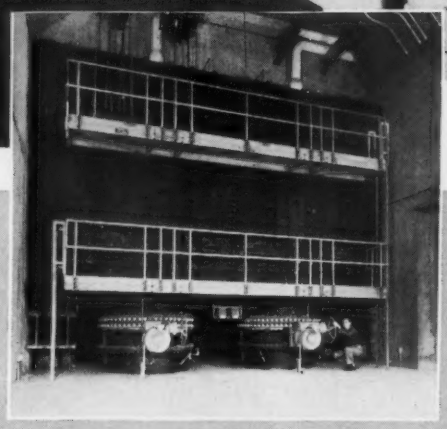
When electric motors, drives and control are properly selected, they become a positive factor in assuring consistent operation, lower investment and maintenance costs, and reduced plant down time.

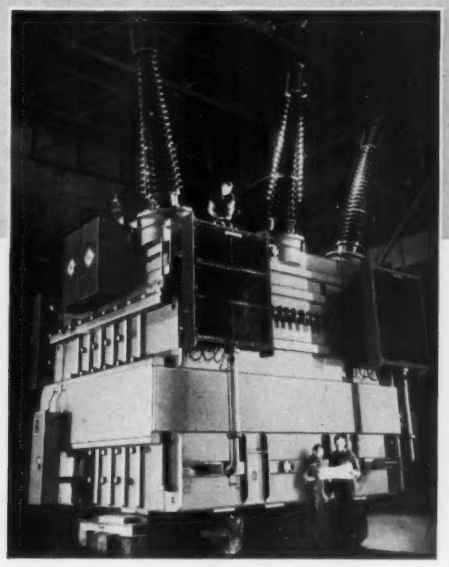


VIEWED FROM THE ROOF of the raw storage silos, looking toward the firing end, the rotary kiln at the right increased the production of cement clinker by 50 percent or by better than 2000 barrels per day.

SLAKED LIME from this 7.5-ft diameter, 180-ft brick-lined rotary kiln balances the flotation agent in copper ore processing. Kiln is rotated at 1.5 rpm with only a 40-hp, four-speed cage motor. Limestone enters the kiln at the feed end (left) and is transformed in two hours into slaked lime at 2300 F.







A-1158-E

Modernize

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A continuing program of electrical equipment modernization is one of the most successful approaches to cost reduction. The *degree* of cost reduction depends upon unit efficiency. Allis-Chalmers equipment has built a world-wide reputation for achieving *higher* system efficiencies created through research-born design advantages!

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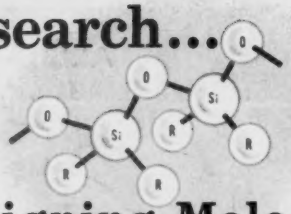
Research...



Designing Molecules

In the rapidly moving area of chemical technology, synthesis plays a vital function in the design of molecules to meet specific requirements. The formation, isolation and purification of a compound are necessary steps before its physical and chemical properties can be determined.

Chemists are seeking to improve high temperature insulating materials through the preparation of new compounds and through an evaluation of the physical and chemical properties of known compounds.

These materials are of a polymeric nature and must be capable of withstanding the environment to which they are subjected. Polymers are long-chain molecules synthesized from a repeated unit of atoms. Examples of such molecules are the silicones, in which atoms of silicon are linked together through oxygen bridges; versatility in this basic polymer is provided by the type of the functional group, *R*, which may consist of an atom or a group of atoms. Thus, tailor-made physical and chemical properties for individual requirements may be obtained through the functional group.

Today, designing of molecules is a standard procedure in the development of new chemical compounds needed to advance technology in all fields of industry.

by D. T. HAWORTH
Research Laboratories
Allis-Chalmers Mfg. Co.